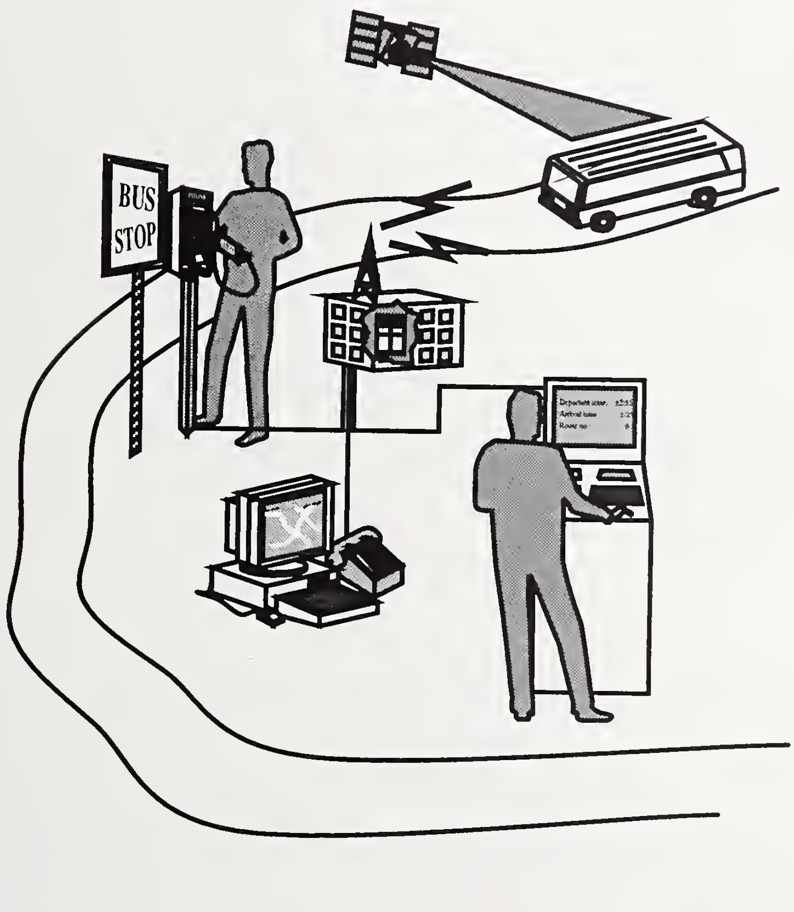
U.S. Department
of Transportation

Advanced Traveler Aid Systems for Public Transportation

The Intelligent Transit Mobility System (ITMS)

September 1994



FEDERAL TRANSIT ADMINISTRATION

Advanced Traveler Aid Systems for Public Transportation

The Intelligent Transit Mobility System (ITMS)

Final Report
September 1994

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METRIC / ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectares (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gr)
1 pound (lb) = .45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x - 32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
1 hectare (he) = 10,000 square meters (m^2) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gr) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH-CENTIMETER LENGTH CONVERSION

INCHES	0	1	2	3	4	5	6	7	8	9	10

CENTIMETERS 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 | 25.40

QUICK FAHRENHEIT-CELCIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and/or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50. SD Catalog No. C13 10 286.

Executive Summary

Information is an essential element of urban public transportation services. The manner by which information is managed and presented has great effects on the image, attractiveness and, consequently, the ridership of public transportation.

In the case of a transit trip, the traveler is responsible for obtaining the tables of schedule and fare and interpreting it to develop a trip itinerary. Further, the availability of a return trip must be checked in order to initiate a trip by transit. Compared with a trip by auto, a trip by transit imposes a much greater task in trip planning on the part of the traveler.

For a transit system which has a complicated multi-modal network, interpreting the schedules and making an itinerary, which usually involves transfers among different modes (including a check for return trip), demand significant effort and time to the non-captive riders. Lack of systematic and consistent information is one reason that many transit systems in the U.S. are used only by the captive or repeat users who are familiar with the services.

With advances in computer and communications technologies, however, it is conceivable to devise a system which delivers information of the transit services and operating status to the potential users at the time when they need it. The information can be tailored to individual users and presented in a form which is only relevant for decision making of that time. We call this system an Intelligent Transit Mobility System (ITMS). The following is a concept of ITMS:

> The central computer of the transit agency stores information of schedules, fares, network, schedules of major activity centers and on-going events in the city. The computer also receives the real time information on the operating status of individual transit vehicles and trains. Other city agencies provide information on traffic conditions and weather conditions, etc.
>
> Potential travelers inquire about the possibility of travel by transit using one of interface mediums described below. The nature of inquiries will depend on the trip purposes and circumstance. The system responds with information which is tailored to answer the specific questions and decision situation of the person. The answer can include alternative itineraries and detailed instructions.
>
> Possible mediums that a user can interface with the central processor are e-mail, handheld computer, cable television and voice mail.

The following are possible scenarios of the use of ITMS.

> Schedule and other information of transit service is memorized in a computer, such as home, office or handheld small computers and it is updated by obtaining a diskette which is provided (or sold) as the schedules are revised.
>
> Transit information is disseminated by electronic mail (e-mail) or by cable television to any potential users directly by the transit agency. For large organizations (e.g. corporations, government offices, universities) their computer network supplies the information by their the internal e-mail network.
>
> The operating status monitored by advanced technologies, for example, the Global Positioning System (GPS), and real time information on the delay status, seat availability, and parking space availability at park-and-ride lots, can be incorporated in the information. Further, the Geographic Information System (GIS) can be used to search and display routes in a user friendly manner.

Based on the premise that technologies for ITMS will materialize in the near future, this study identifies the information which ITMS should deliver, and defines the function and structure of the system components. It then evaluates the feasibility with respect to technical and non-technical aspects.

First, the study examines the problems of the present practices of transit information delivery. It points out how difficult for a person to make a decision to travel by transit under lack of information, citing typical scenarios of transit trips. A survey was conducted to determine the information needs under different circumstances of transit travel. Among the findings was the importance of information about the availability of the return trip when deciding to initiate a travel by transit. Information needs are organized for three situations: to obtain general information of the transit services in the area by a first time user, to develop an itinerary for a specific trip by an occasional user, and to determine the necessary actions en-route on transit vehicle.

Second, the study defines the functions and elements of ITMS. ITMS requires four main elements. They are information collection, central processor (central computer), software for decision aid algorithms, and communications and information dissemination medium. For each system element, the existing and potential technologies are evaluated. Many of the information processing and communications elements are similar to those of the on-going intelligent vehicle-highway system. In ITMS, however, individual travelers instead of the vehicle are guided for the entire trip, door to door.

Third, the study examines the issues which are non-technical but important for planning and implementation. The issues include coordination of participating agencies, roles of different parties, financial responsibility, and implications to the life style and general travel habits in urban areas. This is followed by future research issues.

Part II of the project develops three prototypes of ITMS; one, an itinerary builder (called TRANSPAL) residing in a handheld computer; two, an e-mail based wide-area transit information network (called UDBUS); three, a demonstration of the use of GIS for ITMS.

TRANSPAL resides in a "palm-top" computer which is capable of performing most functions of a desk-top PC. It stores the information of transit services and executes software which provides instructions on how to make the specific travel by transit. Given the origin and destination of the trip, desired departure and (or) arrival time, TRANSPAL develops alternative itineraries which are ranked by the number of transfers involved or closeness to the desired times. Among other functions of TRANSPAL is a search capability; given the names of major destinations (such as civic events), it searches for the closest station and any information on the landmarks. The map of transit network can also be shown on the screen.

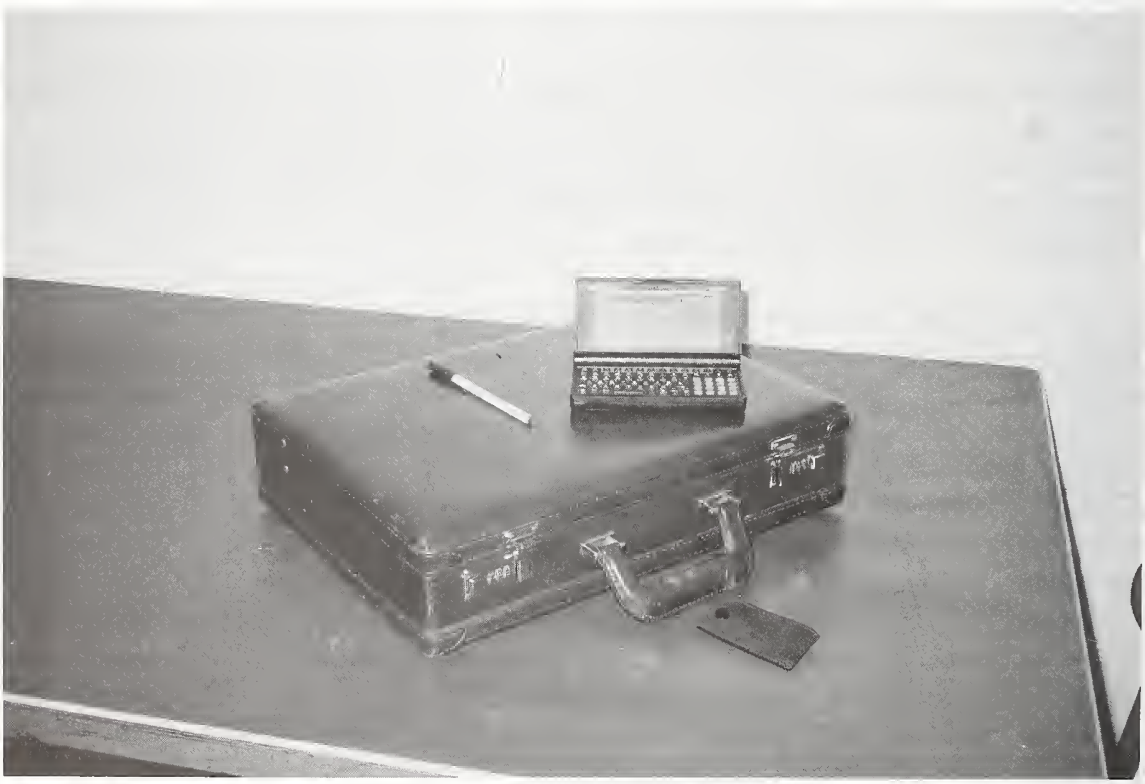
A capability to retrieve information from telephone can be added to TRANSPAL; this would allow the user to carry it to a new city and "down-load" the city's transit information to the computer. For example, a businessman visiting an unfamiliar city is able to have ITMS obtain transit information through a public phone at the airport and use TRANSPAL to find his way by transit.

UDBUS is a prototype of a transit information program which is installed in the mainframe computer network of the University of Delaware. Students and staff can obtain information on the university bus services, including schedule, operating status, itinerary development as well as obtaining day-to-day specific announcement (e.g. snow emergencies, route deviations due to road construction) through the e-mail style access to the computer. UDBUS can be accessed from any computer terminal at library, offices and student dormitories. This is an example of how an office computer's e-mail can be used for transit information purpose.

GIS can be an essential component of ITMS. When used with GPS, GIS will be a powerful tool to identify the location, mapping and geographical data management and display. An example of GIS application to Northern New Castle County transit network display is presented.

Some aspects of the ITMS concept is likely to be realized in the very near future, and products and software for ITMS will be marketed. In fact, limited capability personal travel aids have begun to be marketed. More comprehensive aspects may take a longer time to materialize. ITMS will bring about significant changes in the public's perception of how to plan trips by transit. Especially, ITMS will alleviate the anxiety associated with uncertainty when traveling by transit, which is usually an important deterrent. Travel by transit trip with ITMS can become less worrisome and a more pleasant experience.

Implementation of ITMS, however, requires major changes not only in the organizational structure, but also in the basic philosophy of providing transit service and how its performance is measured. Collecting information and managing computer operations will become critical part of the operation. Transit agency's performance will be monitored much more closely on a day-to-day basis by the public. Further, coordination with other agencies and division of responsibilities will be major agenda of administration. Regardless of modes, the transportation service will no longer be limited to supply of facilities and operation of vehicles; service will begin when a traveler conceives a trip and end when he/she completes the trip, guiding him/her decision making, itinerary preparation and actual travel, anxiety free.



Photograph of Prototype ITMS
(Hand-held transit information computer)

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Part I

THE CONCEPT, DESIGN AND IMPLEMENTATION OF ITMS

Chapter 1

INTRODUCTION

Healthy growth of public transit and the city in the U.S. have long been hampered by the dominance of the automobile oriented transportation policy. Today, we are faced with the consequences of this auto dominant society which is represented by, among others, congestion, flight of downtown businesses, increased use of energy, and a variety of environmental problems. While the blame can be placed largely on the past practices and policies which favor the movement of the automobile, the operating practices of the transit system in the U.S. have also contributed to the decline of transit use and have encouraged the auto dominance. One of the reasons because of which public transit is unattractive today is the lack of and poor quality of information about the service and facilities offered.

It is puzzling to find this poor state of transit information in the U.S.,considering the fact that this society uses some of the most advanced techniques for marketing and advertising commercial products and services. Effective dissemination of information on transportation services is essential to promote a balanced use of different transportation modes, which is the underpinning of the ISTEA (Intermodal Surface Transportation Efficiency Act, 1990) legislation.

This report presents the findings of a project which has developed an innovative system to improve public transportation information dissemination. This information system is called Intelligent Transit Mobility System (ITMS). ITMS provides the transit user with "intelligent" decision support for the choice of mode, route, arrival and departure times as well as the general information on transportation services in the region. The scope of this study includes: (1) the conceptual framework of ITMS, (2) a study of transit user's information needs and decision process, (3) a review of technologies available to implement the ITMS, (4) the structure of the decision aid algorithms, (5) examination of issues related to the ITMS implementation, and (6) development of prototypes of ITMS. Part I covers all of these subjects except the development of prototype. Part II explains the prototypes ITMS and their operations.

Chapter 2

INTELLIGENT TRANSIT MOBILITY SYSTEM (ITMS)

Planning to travel involves a myriad of decisions under uncertainties. In the case of travel by public transportation, in particular, the user has no control over the schedule, route, and the locations of stops (or stations). Hence, information about the availability of the service and the operating status is crucial for deciding on transit as the mode of travel. Today's travelers demand greater precision and expediency in obtaining information. Thus, efficient and effective delivery of information is essential to encourage the public to use transit and to increase ridership. This chapter defines the concept and role of ITMS and illustrates how our decision pattern will change with the ITMS environment in the future.

2.1 Objectives

Recognizing that information is crucial to the use of public transportation, our objectives for developing ITMS are the following:

- to improve the availability and quality of information,
- to tailor information to the decision making needs of individual transit users,
- to improve efficiency of information delivery and to device new way to deliver transit information.

The current problems in each of these aspects are discussed below.

The availability and quality of information regarding public transit service has been very poor in the U.S. Let us consider a case in which a person flies to a new city for a business meeting. He/she would notice that information is well presented until the point where he picks up his luggage at the destination airport. At this point, if he wants to travel by transit (particularly the one which is run by the transit agency, not the "airport shuttle" service), great effort is required to find out the location of the bus stop in the airport complex, the bus route, schedule and fare. This process is usually accomplished by asking the people around. By contrast, he will notice that information needed for renting a car is presented in a well organized manner at most airports.

Poor quality of information is also manifested in many other ways including transit schedules and maps which are difficult to understand (inconsistent format among cities), bus stops or train stations which are poorly marked with no information, illogical system of bus route numbering, and often not too helpful telephone information receptionists.

Information for decision making. Information is only valuable when it is used for decision making. In the case of travel by transit, it has been the accepted practice that the user is responsible for obtaining and interpreting the transit information, and setting a travel plan based on the available timetables and route maps. If a transfer is involved along the travel path, the user's task becomes more complicated. Compounded by the poor quality of information available to the user, this task of preparing the itinerary is a factor which is sufficient to discourage the use of public transportation.

Another problem that a transit user experiences is the uncertainty; for example, uncertainty as to the actual arrival time at the destination, uncertainty as to the availability of a seat, and uncertainty as to the security at the station and stops. If the train or bus is delayed, the passenger would like to have information necessary to make a decision to change mode (for example, get-off the train and take a taxi) or trip plan (e.g. cancel the trip). Information and uncertainty have an inverse relationship; the greater the information, the less the uncertainty the user experiences, leading to less anxiety; while the less the information, the greater the uncertainty and the associated anxiety the user experiences.

Methods of delivering and presenting information have also been a source of the problem. The typical method of providing information has been a printed schedule and route map, along with telephone information service. However, the printed schedules are not always available to the traveler when it is needed; sometimes the traveler must request them using a self-addressed envelop, resulting long time gap between the information need and the delivery.

With the advances in computer and communications technologies, transit information can be distributed much more expeditiously to a greater population than was previously possible. For example, the electronic mail system can deliver information to individual office computers or even to homes, and a simple computer program can retrieve and organize the transit information such that only relevant information is displayed and printed.

Further, a hand-held computer which memorizes transit information and retrieves it as the user needs it, could be developed. Cable television could also deliver transit information to individual homes through a dedicated channel.

The objective of ITMS, hence, is to deliver high quality transit information to the current and potential users of public transportation. Emphasis is placed on tailoring information to meet the needs of individual travel decisions. ITMS should be considered a part of FTA's efforts towards Advanced Public Transportation Systems (APTS). ITMS should be integrated into the Intelligent Transportation System (ITS) such that it can form an integrated intermodal information network leading to a new generation of transportation information system.

With implementation of ITMS, benefits will accrue to all of the following four concerned parties: the general public (captive transit riders and choice riders), FTA, transit agencies, and the manufacturers of the electronic devices required for ITMS. Among these parties, the transit users will enjoy the direct benefit and the spin-off benefits will be enjoyed by the manufacturers of the ITMS device. Ultimately, ITMS will promote the growth of public transit ridership with high quality service.

2.2 The Concept of ITMS

ITMS provides information on transit services in a format which is tailored to the specific needs of the individual transit user (existing or potential). It serves the information needs under the following situations.

1. When general information about the transit system in the region is required. This information is needed by potential transit users or by persons new to the region who are contemplating the use of transit. The information includes the network, the schedules, fare structure and general rules for using the transit service.
2. When the itinerary for a travel is developed. Given the requirements for a trip (origin, destination, desired times of departure and arrival), ITMS prepares an itinerary based on the available schedules and route network map. The itinerary may include more than one alternative schedule including different combinations of departure time, the number of transfers, arrival time and fare.
3. When information on transit service is needed in real time. This need occurs when

the traveler is about to initiate a trip or is en-route on the vehicle (also when waiting for the bus or train). The information in this category includes on-time status, seat availability and any change in route. Further, if the vehicle in which the person is traveling is behind schedule, the person may want to know the cause of the delay, the length of the delay and any alternative way of reaching the destination.

ITMS allows the transit user access directly to the information relevant for making decisions during travel. In many cases, however, the desired departure and arrival times are not completely defined by the traveler. ITMS searches alternative travel paths and provides several schedules. ITMS also considers the feasibility of a return trip by transit because the availability of transit service for return trip often dictates the use of transit in the first place.

Components of ITMS, which will be discussed in detail in later chapters, are capabilities: to collect information, to store and retrieve information at high speed, to transmit information, to develop an itinerary for a given set of travel requirements, and to communicate with the transit users. The relationship among these components are presented in Figure 2.1. The following provides a brief narrative of the flow of data in the figure.

The information collection is performed by different agencies, including the transit agency, the police and the highway department. The real time information on the operating status is collected and sent to the central processor.

The central processor stores both the dynamic and static information. The dynamic information is the current operating status and the static information includes schedules, maps, any other additional instructions already published.

The computer algorithm prepares a package of information specifically tailored to the needs of the individual traveler. The information can vary from a simple schedule to a trip itinerary including several options, or an answer to a specific question.

The user interface and communication with the system are performed by various

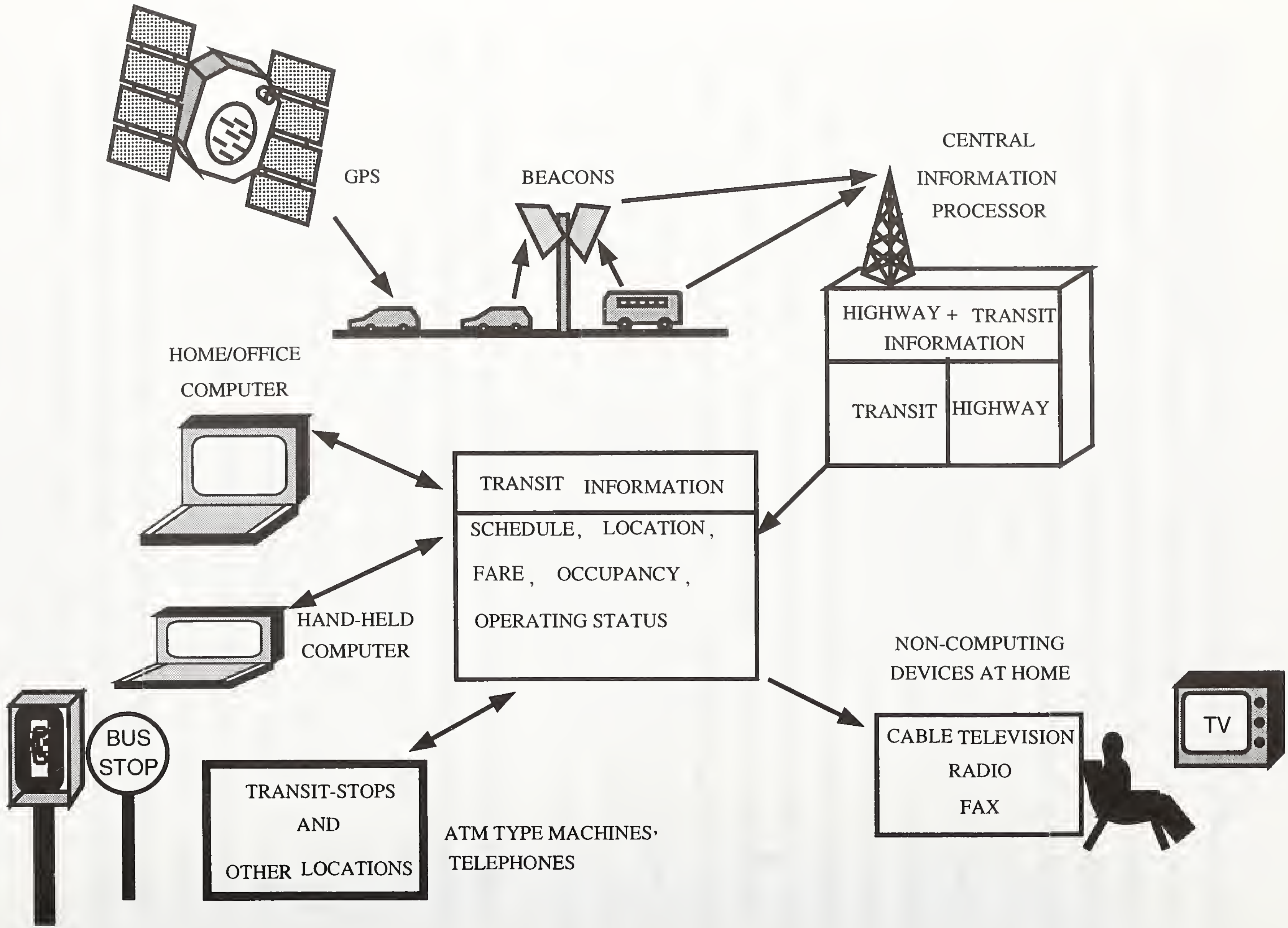

Figure 2.1 ITMS Concept

means including, PCs at home or office, cable television, hand-held computers, and ATM type device at transit stops and major public buildings.

2.3 Target ITMS Market

Transit users can be classified into regular users (captive riders) and choice riders (including first time users). For regular users of transit traveling to/from work or school, a minimal amount of information is required due to their familiarity with the system. Perhaps most important for them is the operating status, such as on-time performance and seat availability.

On the other hand, choice riders, who may be partially familiar with the transit service, or first time users, who are not familiar with the system, need the greatest amount of information. Attracting these groups to transit will be the most effective in increasing transit ridership. Hence, ITMS must be designed to accommodate the needs of these groups. Figure 2.2 shows the information needs for the three categories (captive, choice, and first-time user) of travelers.

2.4 Illustration of Travel under ITMS

In order to illustrate applications of ITMS, three typical travel scenarios in which ITMS would play an important part of the travel decision making process are presented here. The scenarios are: (1) visiting a new city, (2) shopping trip, and (3)business trip during the day.

2.4.1 Scenario 1: Visiting a New City

Imagine a situation in which a person travels from Seattle to Newark, Delaware. He first flies into Philadelphia airport, the nearest airport to Newark, Delaware. During the flight he would want information on the available transportation service from the airport to Newark. Once he/she arrives at the Philadelphia airport, he may want to get more specific information, such as the location of bus stop in the airport, fare, and the travel time. Let us examine how ITMS helps provide information to this traveler, as illustrated in Figure 2.3.

(1) Information needs before arriving. While on-board the airplane, the traveler wants to know the time of arrival at the destination airport, travel options from the airport

Information needs for regular transit users	Information needs for occasional transit users	Information needs for first-time transit users
- vehicle operating status	- schedule	- schedules (frequency and hours of operation)
- possible delay	- transfer requirement days of operation	- availability of return trip
- vehicle occupancy	- routes	- transfer requirement
- space availability	- availability of return tripo	- fares (exact change, pass, discounted fare)
- park and ride location	- availability of discounted fare, monthly passes	- travel time
	- park and ride location	- stop location
		- park and ride location
		- network

Figure 2.2 Information Requirements for Three Groups of Transit Users

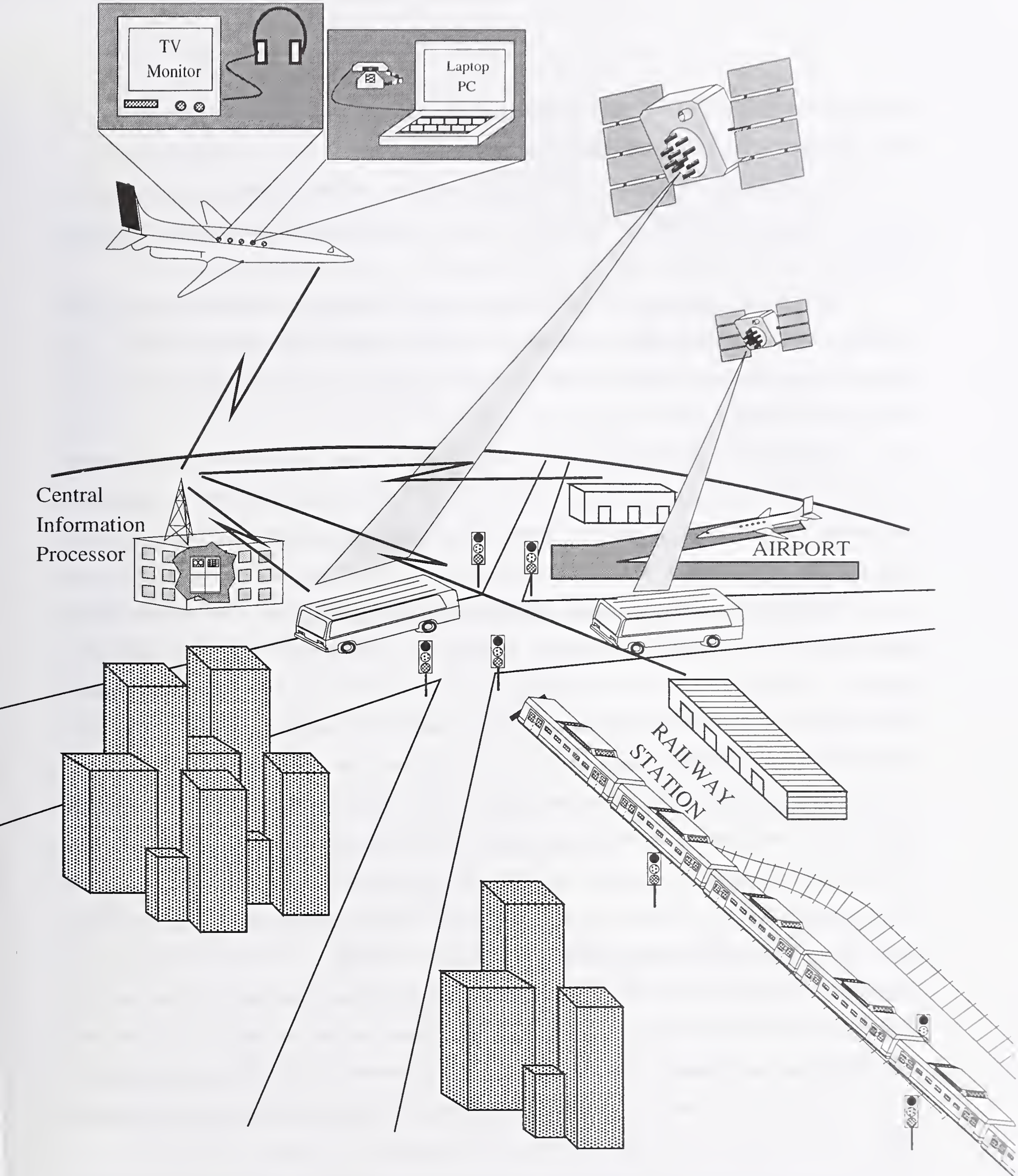

Figure 2.3 Scenario 1: Visiting a New City

(modes of transportation), prices, time, convenience, and possible safety and security of each. Possible methods of obtaining this information are:

Via a hand-held computer. The traveler could access the central transit information center by plugging his hand-held ITMS device into outlets incorporated into the telephones on board.

Via television monitors. The traveler can watch a TV monitor on-board that provides departure times and destinations of the next available public transportation services. The traveler can also watch a GIS generated map of the region on the individualized TV screen to familiarize himself with the area.

Via headset radio channel. The traveler could tune to a channel dedicated to providing information about public transportation for the destination city. A substantial portion of the information could be given using recorded messages and any variability regarding times and routes could be updated.

(2) Information needs upon arriving at the destination airport. Once arriving at the airport, he wonders: Where do I go to take the bus?; Do I need a ticket before boarding the bus?; How do I pay the fare: are they tokens?, exact fare? or a one-day pass available? Which mode will get me to my destination first, transit bus, "airport shuttle", or taxi? The traveler would obtain information by one of the following means:

Via public phone. The ITMS user can plug the hand-held computer into the public phone which delivers the transit information to the computer. The algorithm in the computer can rearrange information such that only the necessary information regarding his trip to Newark will be presented to him.

Via ATM style information terminal. One can also go to an ATM style terminal. On the screen one can view the general area map, travel distance, destination location, and available modes of transportation. The traveler would be able to select his origin and destination by either pointing at locations on a touch screen, by selecting locations from a list, or by providing an address that would be located through the geocoding capability of GIS.

At the completion of a given inquiry, a print-out would be produced. On one side would be a portion of a map illustrating the traveler's final destination and the nearest public transportation stop location, and on the other side would be the scheduled times at which the particular stop is serviced. This would conveniently enable the traveler to make a return trip from that location.

2.4.2 Scenario 2: Shopping Trips

A second scenario refers to a shopping trip made by a person from his/her home. Refer to Figure 2.4 for a shopping trip scenario.

Information required before the trip. The traveler will need to know: where to board the transit vehicle, departure time, travel time, how much to pay, method of payment (exact change, etc.), and the availability of transit service for the return trip. He/she may obtain the information through a home computer, a portable ITMS hand-held computer, cable television, or telephone.

Information needs during the trip. If he/she makes changes to the plan during the trip with regard to the destination or time of return, a hand-held ITMS computer can become useful. By plugging it into any public telephone it can update the travel plan according to the new requirements. It can also display if the changes are feasible for the given transit schedule.

One of the important factors which must be considered when evaluating transit travel for non-work purposes or occasional trips, is whether transit service is available for the return trip. The ITMS can provide the return trip availability so that the person can plan his/her stay at the destination (maybe an alarm feature can be built in the hand-held computer).

2.4.3 Scenario 3: Work Place Transit Information

A third scenario of ITMS use is at school or the office. ITMS provides transit information for a business trip during the day as well as the trip home at the end of the day. An employee could access the transportation information system which is stored in the company's mainframe computer using individual terminals (desk-top or hand-held) and modem devices, as is illustrated in Figure 2.5.

Feasibility of such an information system will depend to a large extent on the capability of the central information processor, its communication with the company computer, and the extensiveness of computer use in the organization.

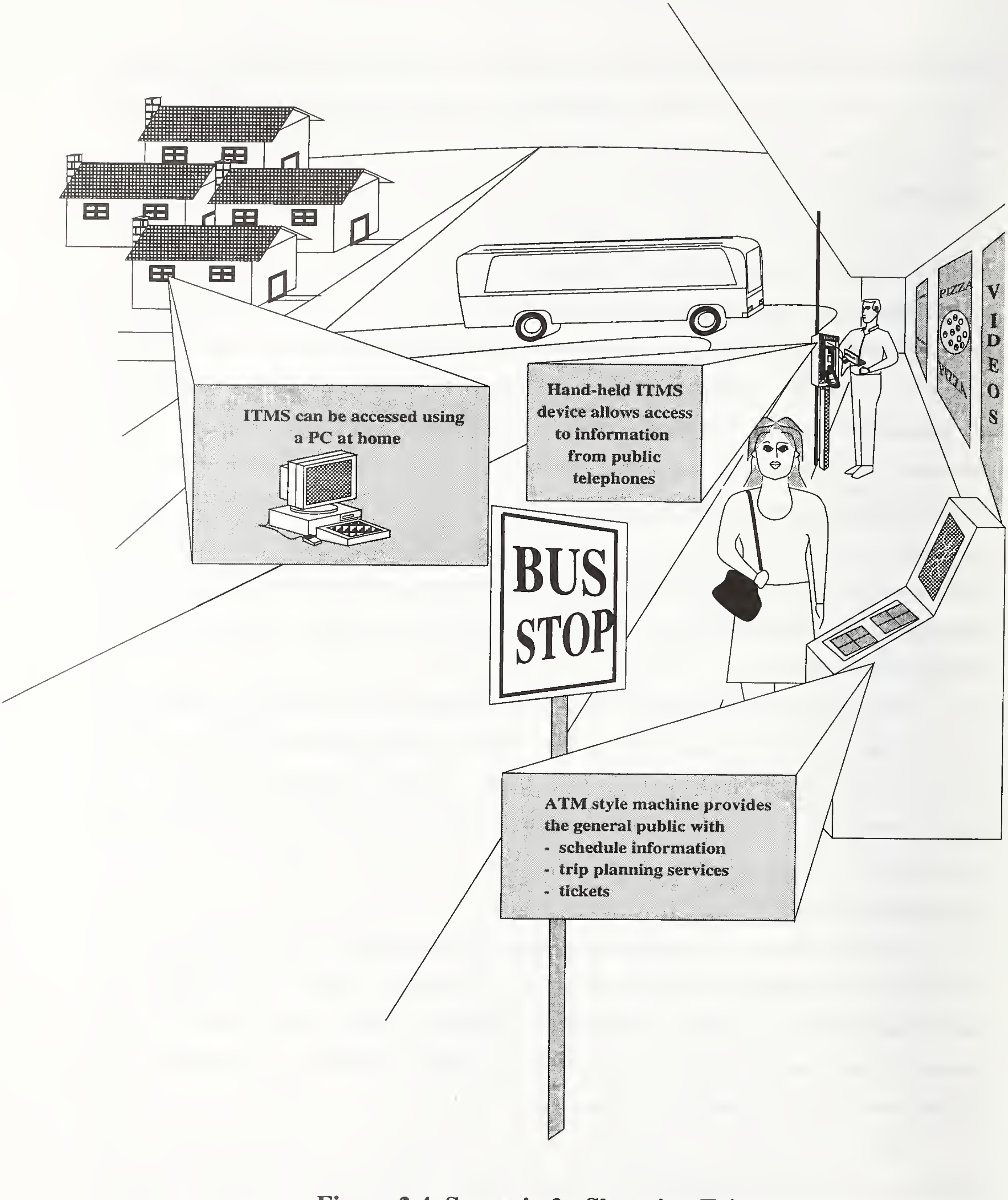

Figure 2.4 Scenario 2: Shopping Trip

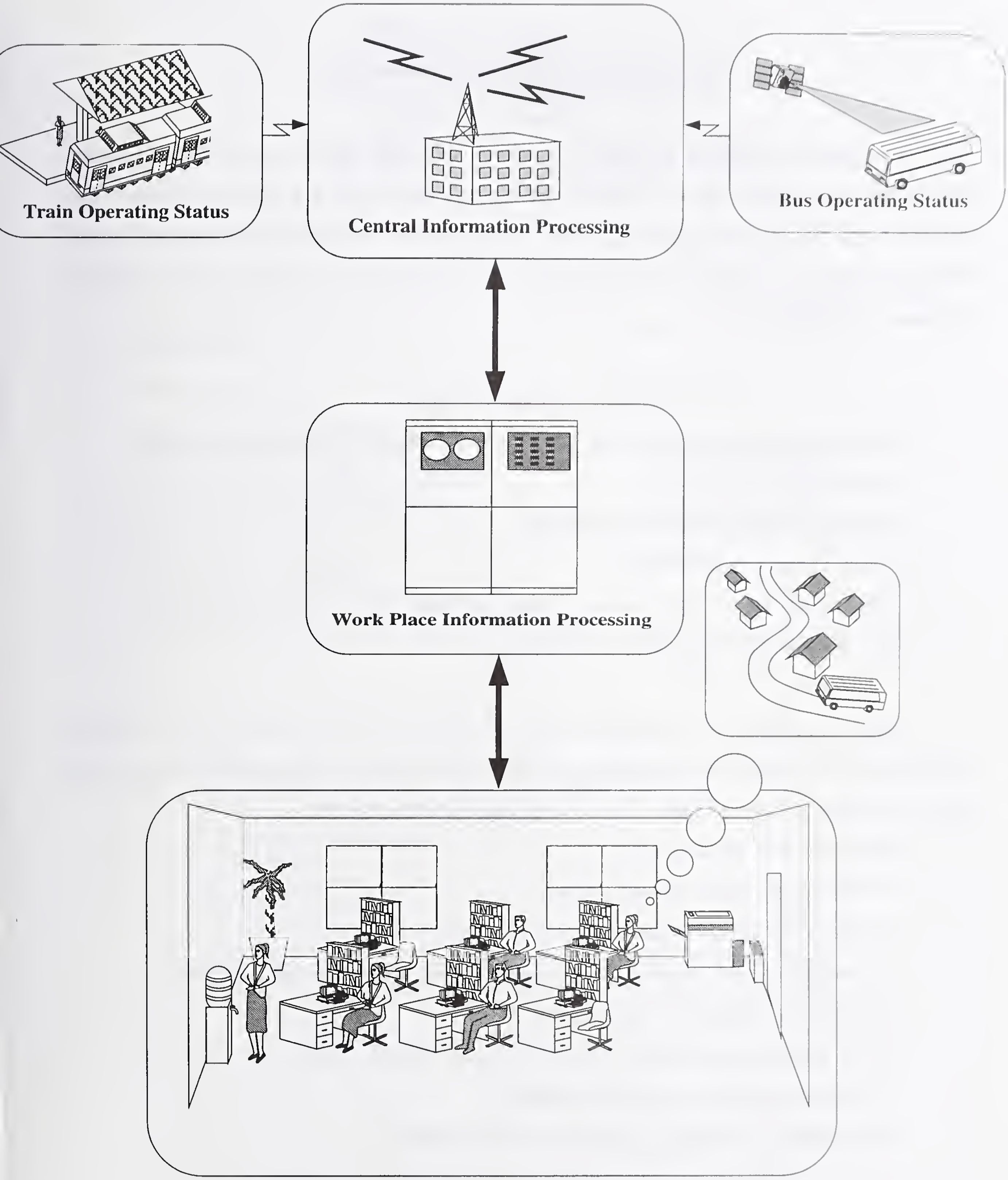

Figure 2.5 Scenario 3: Work Place Transit Information

Chapter 3

TRAVELER'S INFORMATION NEEDS

This chapter identifies the typical questions regarding transit services that a traveler asks before and during the trip. Based on the questions and the types of traveler, the information is categorized into four groups. This grouping is necessary for formulating the ITMS structure. The analysis in this chapter will be tested by an opinion survey which is presented in Chapter 4.

3.1 Typical Questions

When planning a trip a traveler must have at least the following knowledge:

- where to go,
- when to arrive at the trip destination,
- when to make a return trip,
- the importance of arriving and leaving on time,
- the importance of comfort and security.

Based on these, the traveler selects the mode to use for the trip. If public transportation is chosen, the traveler asks the following few more questions before and during the trip. Refer to Figure 3.1 for a typical decision process.

Before the trip, he may ask:

- What transit mode should I take?
- What route should I take?
- At which station should I get-on and at which station should I get-off?
- What time should I be at the stop?
- How much fare is required for the trip and how do I pay?
- Is it possible to come back by transit?
- If transfers are required, where should I transfer?

During the trip, he may ask:

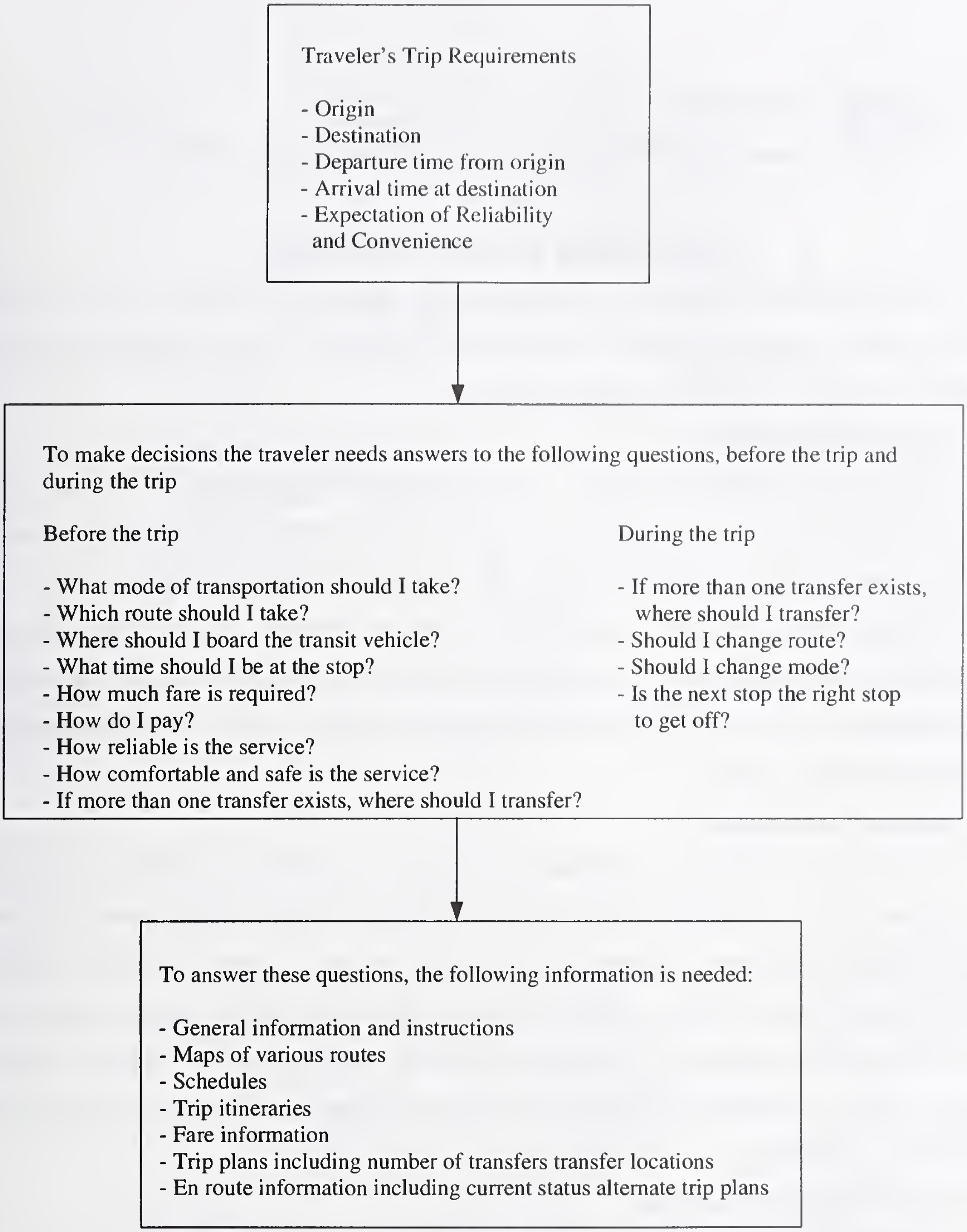

Figure 3.1 Decision Process of a Traveler

- Should I change route?
- Should I change mode? (e.g. should I get-off and take a taxi?)

3.2 Grouping of Transit Information

The information demanded by the transit users (captive and choice) can be classified into four groups: general, schedule, trip plans, and en-route. These information types are illustrated in Figure 3.2 and are discussed here.

3.2.1 General Information

The general information refers to the availability of transportation services in the region. It includes the names and the types of services of different transportation service providers: transit agencies, taxi companies and other travel related agencies in the region along with their phone numbers. Additionally, as shown in Figure 3.3, it provides the users with instructions for using transit and explains the network and the route numbering scheme. This information will be useful for travelers new to the area, tourists and business people as well as the choice users.

3.2.2 Schedule Information

The schedule information, depicted in Figure 3.4, provides a timetable for a given trip. Included in the information are route, fare, schedules, transfer requirements and other instructions such as platform numbers and bus stop locations. Route information includes a map showing the path of the vehicle along with the stop locations, transfer points, fare zones, and important landmarks. The fare information includes the fare structure, transfer charges, method of payment, special rates (peak and off-peak fares) and locations where tickets can be purchased.

3.2.3 Trip Itinerary Preparation

Another level of information that a user needs is a trip itinerary. This is illustrated in Figure 3.5. Given the origin and destination along with the desired departure and arrival times, the user would like to know the feasibility of travel by transit and, if feasible, a specific itinerary. The information in the itinerary includes:

- departure time and arrival time,
- the route and the route number,

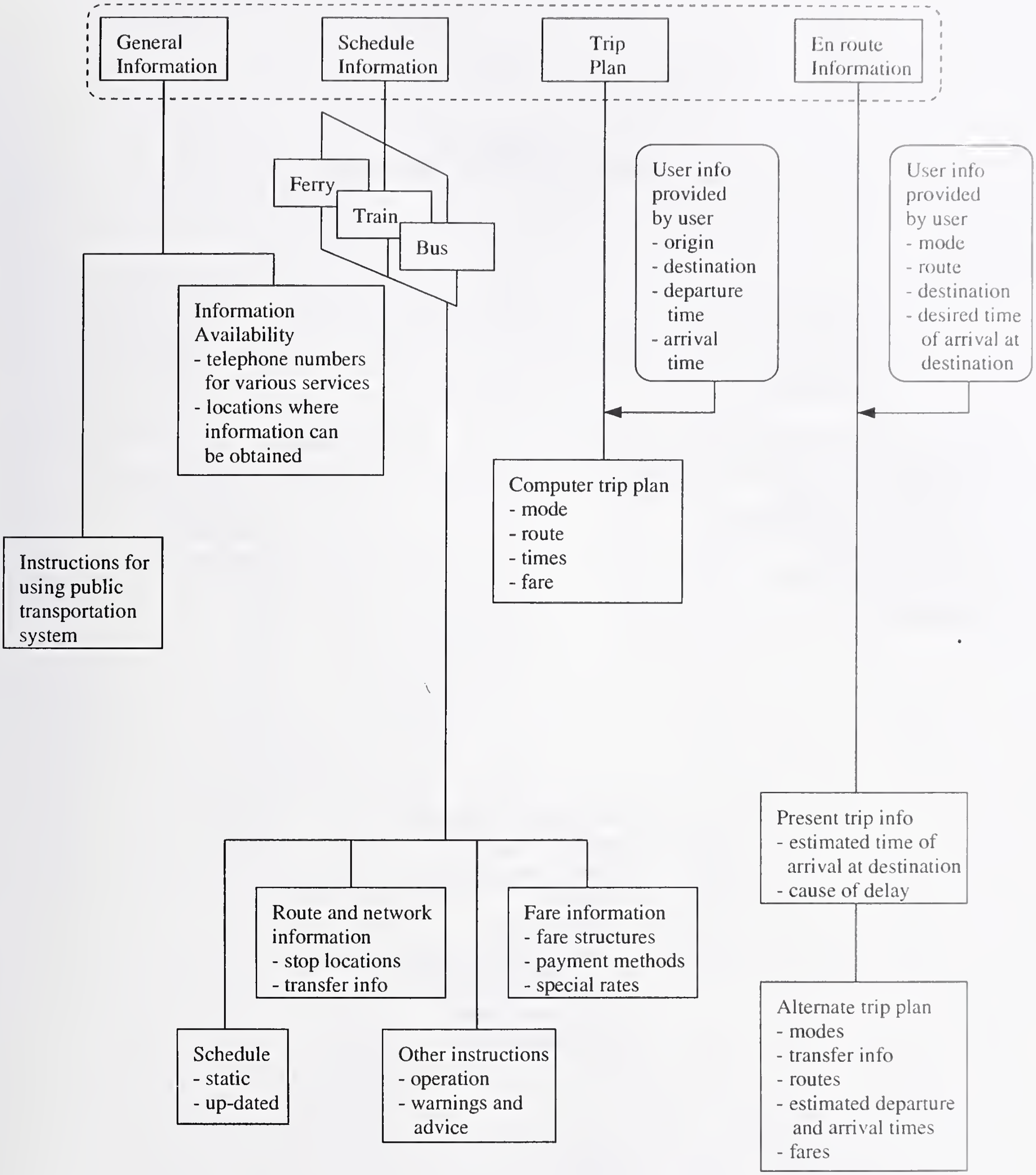

Figure 3.2 Functions of the Traveler Decision-Aid System

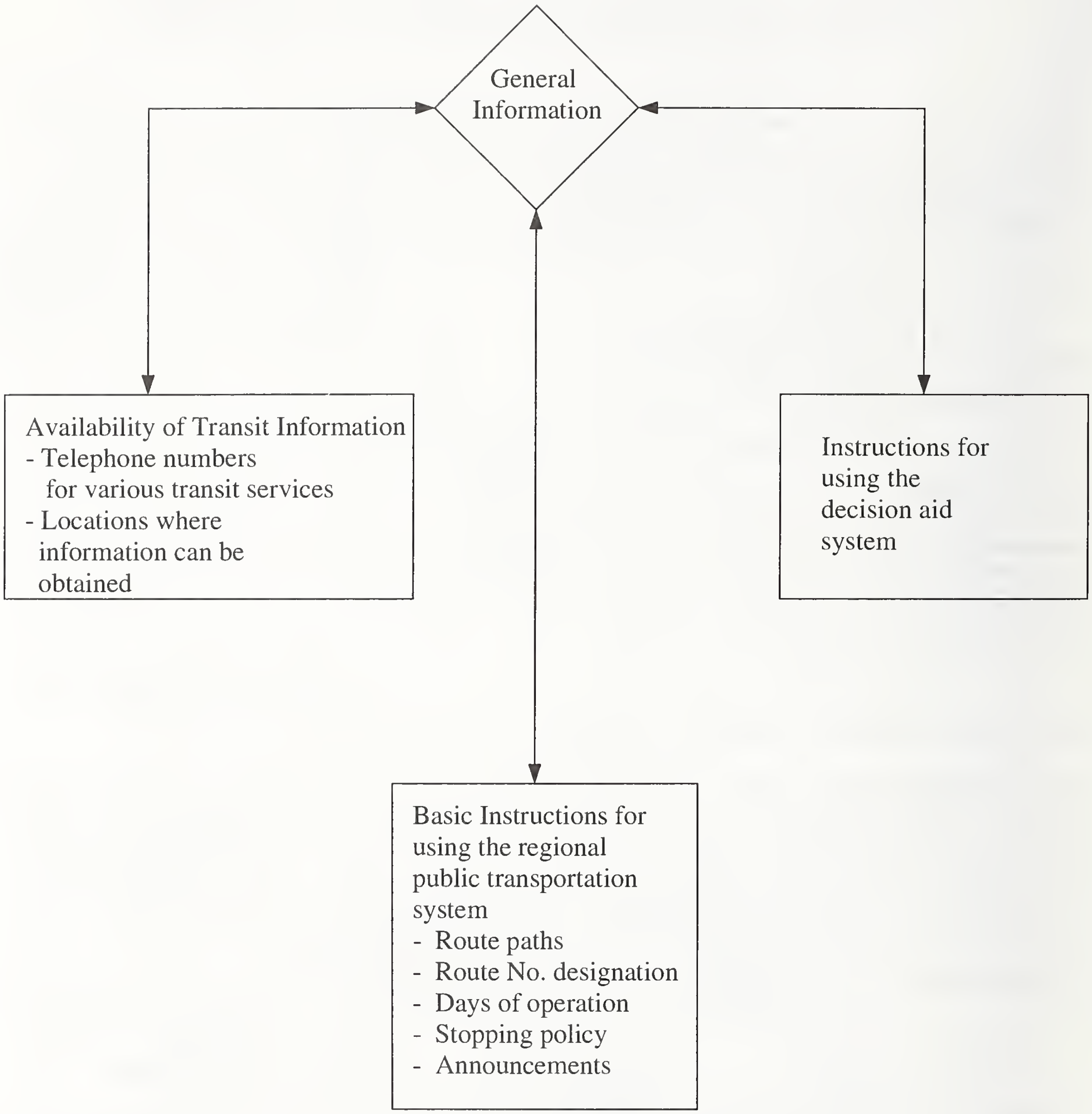

Figure 3.3 Presentation Format for General Information

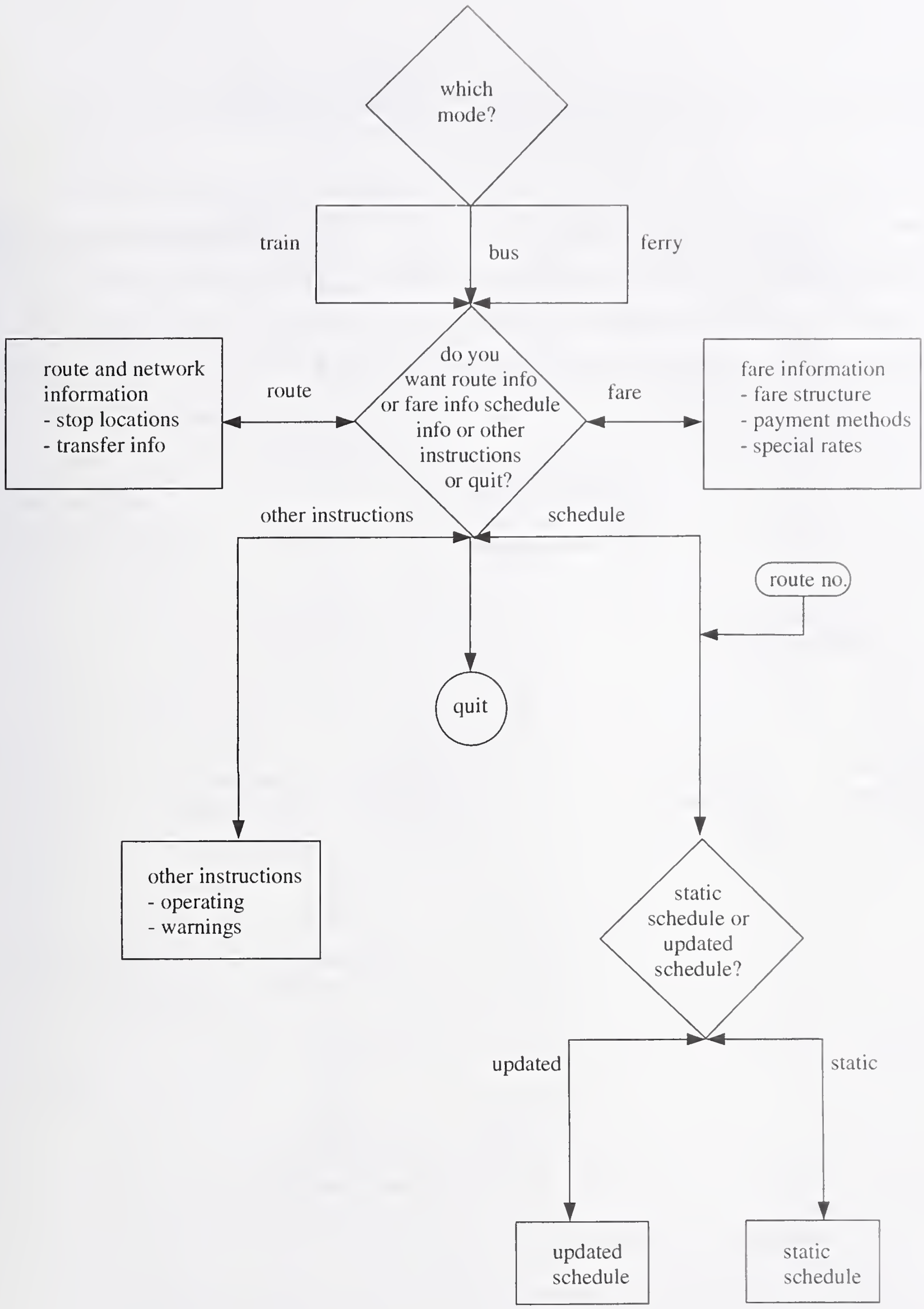

Figure 3.4 Presentation Format for Schedule Information

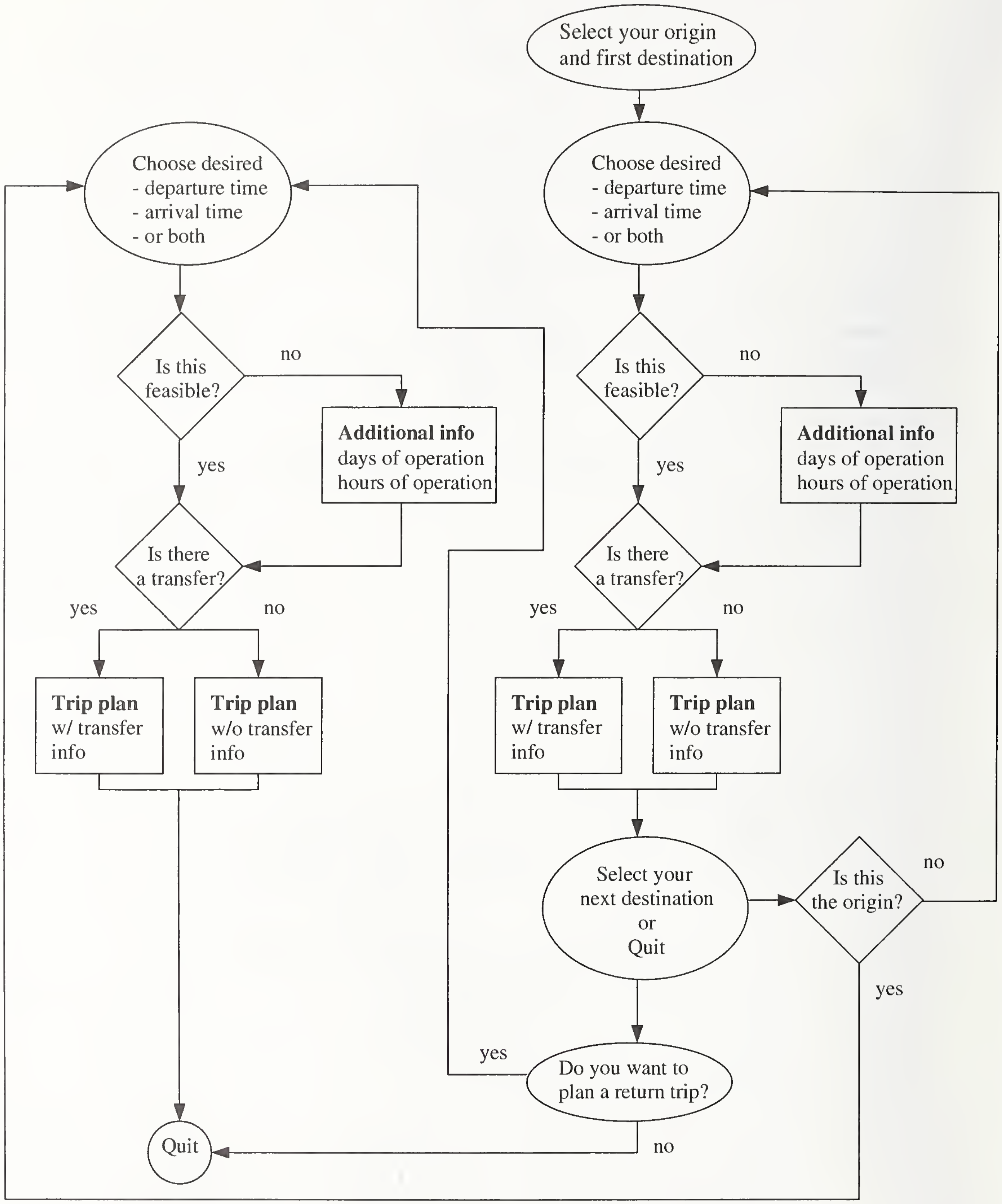

Figure 3.5 Presentation Format for Computer Trip Planning

- transfer points, if any, and their times (arrival and departure time at each transfer point),
- alternative routes and schedules.

3.2.4 En-route Trip Information

The en-route trip information, shown in Figure 3.6, is the current operating status. This information includes the actual arrival time, any delays, the cause of delay and occupancy status. The traveler would use the information to decide on a change in travel mode or route if necessary.

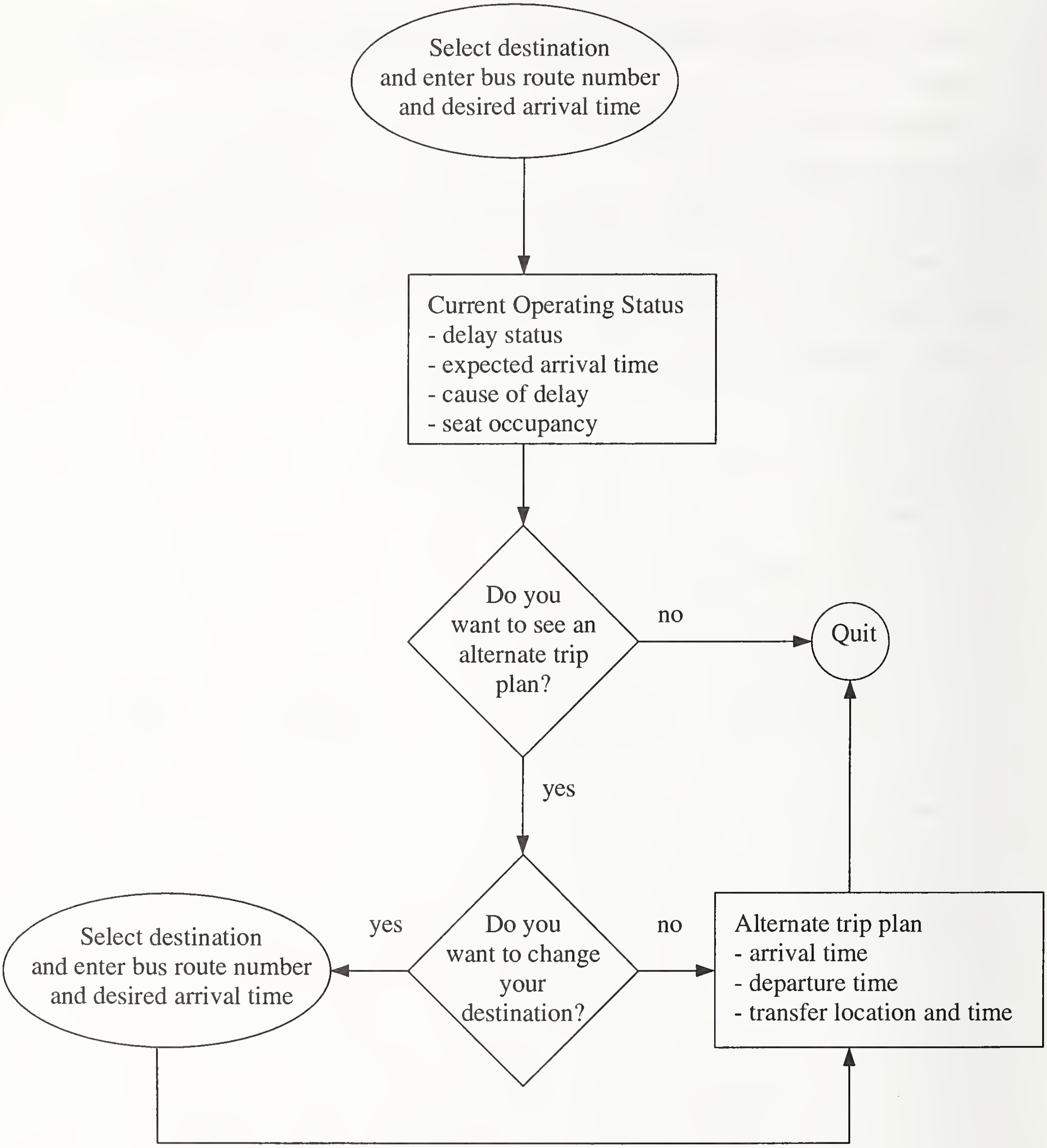

Figure 3.6 Presentation Format for En Route Planning

Chapter 4

SURVEY OF TRAVELER INFORMATION NEEDS

A survey was conducted to assess the needs for information for different travel environments and purposes. This chapter presents the survey questionnaire and the analysis of the survey results.

4.1 The Questionnaire

The questionnaire had six items; each of the items describing a specific trip scenario. A test subject was asked to imagine himself/herself in the scenario and answer the questions. The questions asked the subjects to rate the importance of having a particular piece of information under the trip scenario. They were asked to rate the importance by a number between 2 and 9. The survey was conducted among 78 students in the University of Delaware.

The six situations pertain to obtaining transit information under the following situations:

Situation 1. When visiting an unfamiliar city,

Situation 2. When arrival time is important,

Situation 3. When making occasional trips,

Situation 4. When making an unscheduled spur of the moment trip,

Situation 5. When making an occasional entertainment trip plan for which return trip is uncertain,

Situation 6. When evaluating the option when the transit vehicle is late while en route.

Situation 1 is for a first time transit user. Situation 2 represents a business trip setting, wherein the traveler wishes to be at the destination before a specific time. Situation 3 refers to a shopping or recreational trip taken by an occasional transit user. Situation 4 refers to an unscheduled return trip taken by a regular transit user. Situation 5 describes a return social/recreational trip taken by a first time transit user during the weekend. Situation 6 presents a business trip in which the traveler must make a decision en route about changing route or mode. The questionnaire is presented in the Appendix.

4.2 Survey Results

Table 4.1 (a to f) presents the survey results for situations 1 through 6. Table 4.1 (g) presents the combined survey results for the first five situations.

The departure time, or what time to leave, is always reported to be important; it is greater for first time users and for work and school trips, and less for shopping or social/recreational trips. The availability of a return trip is found to be very important for all users particularly social/recreational and shopping trips, but for home bound trips or trips in which reaching the destination before a certain time is very important, such as a job interview, the availability of a return trip is not reported to be as important.

The frequency of service is cited important for all trips. The information about the location of stops at the destination is somewhat important for first time users, but it is less important for regular or occasional users and social/recreational or shopping trips.

Importance of arrival time at the destination varies greatly with the trip purpose. For trips which the user needs to be at their destination before a specific time, arrival time is obviously very important. For other trip purposes the importance of arrival time is much less. The importance of travel cost varies little for different trip purposes, however, the information about fare seems to become important for longer trips. The time required for transfer, and whether or not a transfer was required, were consistently of little importance among the various trip purposes and user types. These results underscore the fact that the current and potential transit users demand accurate information, particularly the time related information, to use transit service.

TABLE 4.1 Survey Results: Ranking of Importance of Transit Information

(a)

Situation 1: Visiting an unfamiliar city	
Information	Importance (Normalized Average)
departure time from airport	0.89
stop location	0.73
requirement for transfer	0.70
transfer time	0.70
cost	0.66
arrival time at hotel	0.63
availability of a return trip	0.63

(b)

Situation 2: Trip when arrival time is important	
Information	Importance (Normalized Average)
arrival time at destination	0.98
departure time from home	0.87
stop location	0.86
availability of a return trip	0.73
transfer time	0.72
requirement for transfer	0.68
cost	0.55

(c)

Situation 3: Occasional shopping trips using transit	
Information	Importance (Normalized Average)
availability of a return trip	0.85
frequency	0.81
departure time from home	0.75
stop location	0.66
cost	0.65
arrival time at destination	0.60
requirement for transfer	0.58
transfer time	0.58

(d)

Situation 4: Unexpected change in work trip plans	
Information	Importance (Normalized Average)
availability of a return trip	0.89
departure time from school	0.88
frequency	0.83
stop location	0.68
arrival time at home	0.63
transfer time	0.62
requirement for transfer	0.59

TABLE 4.1 (cont.) Survey Results: Ranking of Importance of Transit Information

(e)

Situation 5: Return from an occasional night or weekend entertainment trip	
Information	Importance (Normalized Average)
availability of a return trip	0.94
hours of operation	0.89
days of operation	0.88
departure time of return trip	0.80
frequency	0.80
stop location	0.77
cost	0.75
arrival time at home	0.64
requirement for transfer	0.62
transfer time	0.62

(f)

Situation 6: Transit vehicle is late while en route	
Information	Importance (Normalized Average)
arrival of alternate mode at the final destination	0.92
further delay?	0.91
availability of alternate mode	0.90
departure time of alternate mode	0.88
how late is the current mode running?	0.86
distance to terminal for alternate mode	0.86
distance from current location to final destination	0.69
cost of the alternate mode	0.53
cause of delay	0.47

(g)

Compilation of Situations 1 to 5	
Information	Range of Averages
departure time	0.75 - 0.89
availability of a return trip	0.63 - 0.94
frequency	0.80 - 0.83
stop location	0.66 - 0.86
arrival time	0.60 - 0.98
cost	0.55 - 0.75
transfer time	0.58 - 0.72
requirement for transfer	0.58 - 0.70

Chapter 5

STRUCTURE OF ITMS: FUNCTIONS AND COMPONENTS

ITMS consists of five main components. They are:

1. Information collection
2. Central information processor
3. Communication (transmission of information)
4. Decision-aid algorithm
5. User interface and information dissemination

The interactions among these components are illustrated in Figure 5.1. This figure shows how the information flows from the collection points to its delivery to the user. The functions of each component and the relationships among them are discussed here. A review of available technologies associated with each function will be presented in Chapter 6.

5.1 Information Collection

Information on transit service may be categorized in two classes:

- The basic information on the transit service in the area (this is called static information in this report), and
- Real time information on the operating status.

Static (basic) information pertains to schedules, maps, fare structure and any other information which will not change in the foreseeable future. Any temporary changes to schedules, maps, fare structure and key features of major bus stops are considered part of static information in this report.

Real time information pertains to the current location of the vehicles in the network, its on-time (or deviation from schedule) status, the traffic conditions in the network, and the level of seat occupancy in the vehicle. This information is obtained by the transit agency, the police, and the highway department through the ITS communications network. Means of collecting the real time information of the vehicle locations are discussed in Chapter 6.

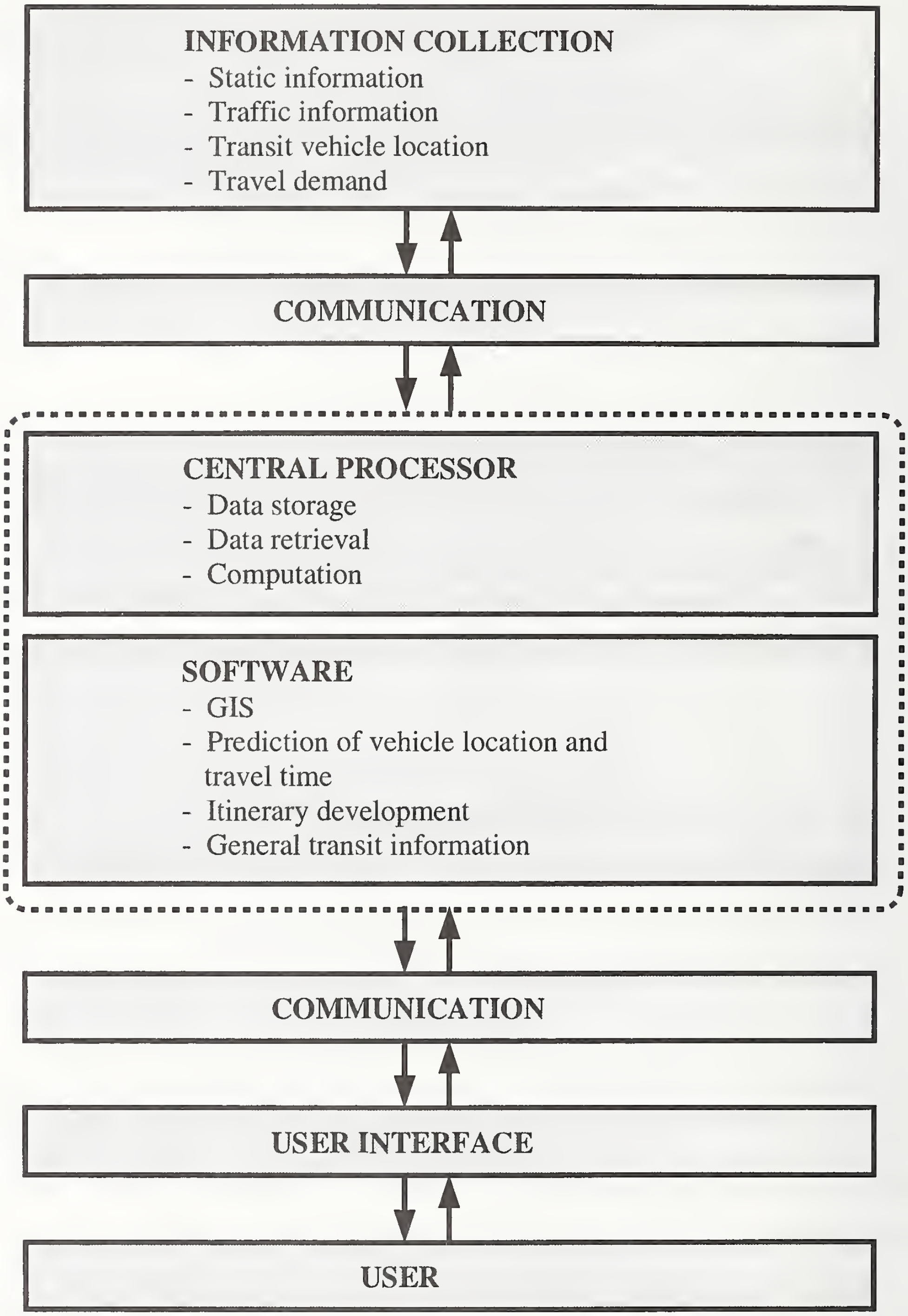

Figure 5.1 Functional Components of ITMS

5.2 The Central Information Processor

The information collected is transmitted to a central processor (central computer) where it is processed and reformatted to meet the different demands of individual travelers. The central processor may be integrated with that of the ITS information center or be located at the local transit agencies. The main functions of the central processor are:

1. Storage/retrieval of information
2. Execution of different algorithms to transform the information to a form useful for travelers' decisions.

As for computation, the following functions are envisioned:

- Prediction of vehicle arrival times,
- Prediction of vehicle operating status and propagation of delay,
- Determination of transfer possibility,
- Determination of operating statistics of the transit services including the delays, demand, reliability, and
- Preparation of trip itinerary for a user. (This function will be performed by the central processor only if the user interface is a non-computing based device; otherwise, the user interface will prepare the trip itinerary.).

5.3 Communications

Communications involve transmission of real-time information from the monitoring sites (both transit and highway) to the central processor and from the central processor to the transit users. Transit users may have access to the processor through personal computers or through the mainframe computers of the companies and organizations receiving the information. Availability and reliability of technology and its management are expected to be critical to successful ITMS implementation. The specific technologies for communications are discussed in Chapter 6.

5.4 Decision-aid Algorithms

The algorithms deal with retrieving information stored in the central processor and "packaging and tailoring" it to assist individual travel decisions. The algorithms:

- Provide the general information about the transit services in the region,
- Present transit schedules and fares for a particular origin-destination pair for a particular time period,
- Display the route map of the trip which serves a given trip, and
- Prepare a trip plan including alternative itineraries.

5.5 User Interface and Information Dissemination

The output of the algorithm must be presented to the user in a clearly understandable manner. The user interface is the only window through which the user interacts with the system. This task can be performed by a PC at office or home or by a portable hand-held computer which can be carried by the traveler.

In addition to the computer based interface, cable television and telephones may be used to disseminate the information. Because ITMS focuses on assisting needs of individual transit users, the user interface must be capable of tailoring the information to situation-specific needs of the user. A prototype device for user interface is proposed in Part II of this report.

Chapter 6

TECHNOLOGIES FOR THE COMPONENTS OF ITMS

This chapter discusses the technologies for four of the five ITMS components: information collection, central information processing, communications and user interface. The technologies discussed here include both the ones that are presently in use and others that are under development. The final component, the decision-aid algorithm will be discussed in Chapter 7.

6.1 Technologies for Automatic Vehicle Location Identification

Knowledge of the whereabouts of the transit vehicles relative to the person who plans to use transit is perhaps the most important information in developing the successful ITMS. If the current location is not known in real time, it must be estimated from the schedule. In this chapter, we will discuss technologies which are potentially useful for the real time identification of vehicle location.

Five technologies are reviewed here. They are Global Positioning System (GPS), proximity signpost, vehicle-probe, closed-circuit television and dead-reckoning.

6.1.1 Global Positioning System (GPS)

Global Positioning System is one of the most promising methods for performing these tasks. We present the elements of GPS, its applications and limitations.

Elements of GPS. The global positioning system commonly referred to is the Navstar GPS developed by the U.S. Department of Defense. It was originally designed for 21 operational satellites and 3 active spares which continually transmit signals that are picked up by GPS receivers on land, on water, and in the air. Signals from each satellite contain the precise time when the signal was sent, parameters used to define the satellite's orbital position, and a set of almanac constants used to approximate the orbits of the GPS satellites. By comparing the current time in the receiver with the times which signals from four or more satellites were sent, the receiver can calculate its three mutually orthogonal position coordinates. Each GPS satellite is assigned its own unique pseudorandom code enabling the receiver to distinguish one satellite from the others. To maintain the accuracy of the system, the satellites signals are monitored from the ground and correction factors for the satellites' on board atomic clocks and current orbital elements are transmitted back to each satellite on a daily basis [21].

Of the two binary codes sent from each satellite, only one, called the C/A-code (coarse acquisition code) is available free of charge to civilian users. The other, known as the P-code (precision code), can only be accessed by authorized military users. The significance of this is that the C/A-code has a limited amount of accuracy degradation purposely entered into the signal by the Department of Defense to increase positioning errors for unauthorized users. This limits the effectiveness of using GPS for some applications where consistent accuracy is important.

This limitation, however, can be overcome by using what is known as differential GPS. By using two GPS receivers instead of one, the systems accuracy can be significantly improved. Claims have been made that using differential GPS can reduce error down to three meters. This is accomplished by using one receiver as a base station which transmits correction information to the other receiver allowing it to navigate relative to the base station's location [21].

Applications. GPS is currently used for commercial fleet management and railroad freight car monitoring. It has the potential, however, of being integrated into ITMS. It will be possible to display the real-time transit vehicle location on GIS-based maps in the central processor and on personal (desk-top or hand-held) computers of travelers. The information from GPS will enable the ITMS to estimate the speed and predict the times of vehicle arrivals. Incidentally, these activities are already under experiment for ITS.

By incorporating a GPS receiver into the traveler's hand-held device more applications become possible. A traveler planning an immediate trip would no longer need to enter the origin of his trip. He could simply enter an address for the destination and the geocoding capability of the Geographic Information System (GIS) would determine the coordinates for that location. The traveler would then enter the desired time of arrival. The present position determined by GPS would automatically be sent along with the other information to the central processor where scheduling and route selection algorithms would determine appropriate routes.

GPS could even be used to determine the user's walking speed and estimated time of arrival at the transit stop. Commonly taken routes could be stored for future reference. For travelers visiting cities with many tourist attractions or historic sites, GPS could be used as a triggering mechanism to automatically display information on the hand held device as soon as the traveler is within a certain proximity to the site [21].

An additional use for GPS in ITMS is as an aid for notifying the appropriate authorities of an emergency. In case a person felt threatened he/she could punch in a code on the hand held device in a manner similar to making a 911 call. GPS would allow the authorities to know the precise location of the person needing help.

Limitations of GPS. The GPS receiver must track an adequate number of satellites. If the required line-of-sight reception is not maintained between the receiver and the satellites a position solution cannot be obtained. In urban areas with many high-rise buildings the ability to position transit vehicles would be greatly reduced. To compensate, other technologies such as dead reckoning or proximity signposts, can be used in conjunction with GPS to provide uninterrupted positioning.

Another performance limitation of GPS receivers is the required time to first fix. The time to first fix is the time required for a receiver to obtain its first successful position fix [21]. This time can range from less than two minutes to more than four minutes. For a personal portable GPS receiver which does not have a continuous power supply, each time the unit is switched on, the user must wait for a first position fix. This poses more of an inconvenience than a limitation.

6.1.2 Proximity Signposts

Proximity signposts determine the proximity of a vehicle to a location device [34]. Signposts can be categorized as either sharp signposts or broad signposts. Sharp signposts locate vehicles within a close proximity while broad signposts locate vehicles in a greater range. The signposts work in coordination with sensing devices which are placed close to them. Instruments generally classified as sensing devices include radio signal based, optical scanners, or electromagnetic induction loops. The first two devices are generally mounted atop poles and the last device is buried in the pavement.

Microwave and radio frequency devices are generally used for broad proximity sensors whereas optical and induction loop devices are used as sharp sensors. When a vehicle reaches an area covered by the signpost with a radio or a microwave device, it communicates with the signpost. There are two ways by which a vehicle communicates with such a signpost; either the vehicle broadcasts a coded message beam to the signpost or the signpost sends a similar message beam to the vehicle. The vehicle location information is then either processed in the vehicle itself or it is processed by the signpost device. Then the information is dispatched to the central processor. If vehicle location information is not required immediately, it can be stored by the signpost device and can then be used for future reference [34].

Optical scanners emit a laser beam or an optical beam to read the bar code label on the vehicle. The scanned information is sent to the central information processor to locate the vehicle. This technology has limited applications as the optical beam must trace itself back to the scanner. Poor weather or road conditions, old or worn out labels are possible sources of inaccuracy in the location information.

Induction loops are buried in the road pavement at known locations. When a vehicle passes close to the loops, it transmits a coded vehicle identification signal to the loop. The loop sends this signal to the central information processor and the computer then determines the location of the vehicle by the known location of the loop.

6.1.3 Vehicle-probes

Vehicle-probes is a system in which the vehicles themselves are used as traffic flow probes that indicate the traffic flow characteristics. The vehicles transmit information regarding the location, speed, and other parameters such as vehicle occupancy to the central computer, which uses these to estimate the traffic flow characteristics and provide information to transit users.

II Morrow Vehicle Tracking System provides a Loran C based system which monitors the location and movement of vehicles in a fleet. In this system each vehicle picks up a signal from a U.S. government operated navigation network. The systems control device processes the signal and feeds it into a high resolution TV monitor on which a map of the area is displayed.

6.1.4 Closed Circuit Televisions

Closed-circuit television cameras are mounted atop tall poles (usually around 40 feet). These cameras "survey"the street and send back pictures to the monitors at the Traffic Monitoring Center. The controllers monitoring the images received from the closed-circuit cameras can predict traffic congestion or incidents.

AUTOSCOPE, the system developed at the University of Minnesota, is a merger of the closed-circuit TV with the loop detectors. In this system, the locations of the loop detector are displayed on the television screens, and the required traffic flow characteristics are derived for these locations using the video information available from the closed-circuit television cameras mounted at the sites. This system not only detects the presence of the vehicle but also its speed and flow density. These parameters allows the computation of traffic flow and estimate congestion level, and thus the travel time.

6.1.5 Dead-reckoning

Dead-reckoning is the process by which the location of a vehicle is computed using the physical laws of motion. The vehicle operator transmits the vehicles location coordinates to a dispatcher who notes the time and location of that vehicle. Devices which are used for determining the vehicle location, speed, time and odometer reading are the compass, gyroscope, odometer, clock and a microprocessor. A radio is used for transmitting the information to the dispatcher. The cumulative distance that the vehicle travels can be easily obtained from the vehicle.

The other vehicle location methods are quite capital intensive. Hence, dead-reckoning may be attractive, since it requires no sophisticated communication systems. One of the disadvantages associated with dead reckoning is that it is prone to inaccuracy caused by the road. The traffic conditions, vehicle wheel slip, vehicle tire pressure and the road surface affect the accuracy of the vehicle sensors [34]. To reduce the possibility of errors from such sources, the operator continually sends the vehicle location to the dispatcher for the purpose of correcting the errors.

6.2 Technologies for Central Information Processor

The central information processor will need to have a capability for storing the information received, performing computations to yield the necessary parameters, organizing the results of computation in a user-friendly manner and transmitting the result to the user interface device.

Geographic Information System (GIS). Because many of the tasks required by ITMS deal with spatial information, the integration of a geographic information system (GIS) will be of great benefit. GIS is defined by Huxhold as "a computerized system for capture, storage, retrieval, analysis, and display of spatial data."[16] GIS stores and retrieve massive spatial data in an efficient manner, performs spatial relationship analyses and provides visual display. The way in which spatial relationships are established depends on the cartographic data linking one location to another. Cartographic data can include streets, rail lines, or waterways and are generally stored in a GIS as a geographic base file.

In the case of public transportation, the data sets required for an analysis include stop locations, schedules and fare. The spatial attributes associated with the data are locations. Thus the stop locations of public transportation and the origins and destinations chosen by the traveler can be related to one another based on their address. The spatial relationship among locations is determined by using a coordinate system. Coordinate systems commonly used include longitude and latitude, state plane, and universal transverse mercator (UTM)[16].

The two most common geographic base files are the DIME files and TIGER files. Both were developed by the U.S. Census Bureau, however, the TIGER files are more sophisticated and comprehensive. They include geographic features scanned from U.S. Geological Survey (USGS) maps such as roads, railroads, and rivers, census geographic area codes, address ranges, and latitude/longitude coordinates for all points [16].

Applications. There are several ways by which GIS could be of benefit to ITMS. With the use of GIS, ITMS can locate the origin and destination of the traveler easily. ITMS can translate the addresses into the coordinates and find the appropriate bus route which best suits the oigin-destination pair. GIS would not only be able to inform the traveler about the boarding and alighting locations of the transportation system, but would also graphically indicate the approximate distance from each stop to the origin and destination.

Route selection algorithms available in a GIS could also be applied to ITMS. Not only could this be useful for choosing the route on one mode of transportation but also for choosing the most direct path between stops when transferring from one mode to another.

The usefulness of GIS is further enhanced by its capability to display accurate maps which help the traveler to visualize where they are and where they want to go. Another way to aid the traveler is to provide an option to view a graphical layout of bus terminals, subway terminals, and even airport terminals.

Parcel maps available in a GIS can graphically display buildings and land parcels along with streets. Used in conjunction with data on land and building use, a GIS can show travelers the locations of shopping centers, hospitals, municipal buildings, parks, day care centers, churches, and universities.

Limitations of GIS. Despite the promise of application, often the greatest barrier to implement GIS is the cost. Some general rules presented by Antenucci et al. suggest that the main cost involved in establishing a GIS is the data base development. This is followed by the cost of software maintenance and upgrade, whereas the cost of hardware and software represents a small portion of the overall cost[1]. To overcome this obstacle and to gain greater benefits from the implementation of a GIS, consideration should be given to development of a system which could, in addition to its transportation application, be used by many governmental departments throughout a region in areas such as health and safety, public works, and urban development. In this way some of the fixed costs of a GIS could be spread out among various sources of funding. Antenucci et al. also discuss a comprehensive methodology for implementation of a GIS.

The growing popularity of GIS in recent years has encouraged many urban and regional governments to compile their records into computer data bases. Along with new data processing capabilities in GIS, integration of GIS in new areas such as ITMS should become easier in the near future.

6.3 Technologies for Communications

This section discusses technologies which can be used to transmit information in the operations of ITMS. Communications in this section refer to the communications between the user and the central processor.

6.3.1 Cellular Modem

The cellular modem is a device that connects the data terminals to the voice communication channels. Modems are commonly used for linking up personal computers to the telephone network. By linking up personal computers to the voice communication channels it is possible to transfer data from another data terminal to the personal computer. This is relevant for ITMS as it is simple to use, is easily available in the market and can link up the user to any licensed data network.

The voice channels constitute an analog circuit and the data is in the digital binary form. To transmit digital signals over analog circuits, it is necessary for the data transmitter to modulate a voice-frequency carrier signal and for a data receiver to demodulate this signal [10].

The speed of data transmission depends on the type of modulation; and the type of modulation depends on the requirement. Though cellular modems are in extensive use, they co-exist with the possibility of network saturation and a high "noise to signal ratio". The present protocol standard using the telephone modem is of the order of 19.2 Kbps. Protocol refers to the accepted rate of transmission of information on computer networks. Some telephone companies offer 56 Kbps digital telephone links [23]. With the onset of very fast rates of transmission (which is nearing completion), it will be possible to improve on the current modem protocol speeds.

6.3.2 Wireless Communication

Another method of transmitting a large amount of information from the central processor to the individual users and back is by means of wireless communication. At present wireless communication requires authorization from the FCC and there is immense competition for the limited spectrum. To increase the capacity of the radio spectrum, the following options exist:

1. Cellular frequency isolation [35],
2. Digital signal transmission as opposed to analog transmission, and
3. Spread spectrum technology.

In cellular frequency isolation the area receiving signals is divided into many small cells; each cell can be as small as 3 to 4 feet across. Adjacent cells use different frequencies though cells on opposite side of the grid can use the same frequency. Thus, cellular frequency isolation would require several antennas around the area being served by the same frequency. It is, however, expensive to subdivide a cell and add new antennas and telephone lines to handle new calls.

To overcome the expenses involved with the cellular frequency isolation method, digital technologies that use sophisticated compression techniques are available. At present, digital converters are being used for modelling the human voice box to provide for optimal compression of conversation. Although wireless communication is fast and efficient, it has certain disadvantages as well. While conversing on the telephone it may not be possible to notice the few bits lost due to wireless communication, but losing a few bits during data transfer can be disastrous [23]. Thus, one needs to weigh the competing costs of having digital wireless communication to overcome the problem of noise in data and to continue with analog transmission with the associated cost of losing data accuracy.

Also, the FTA may request a low frequency band-width in a high frequency spectrum such as the 1.8 to 2.2 GHz spectrum. This is an advantage because lower frequencies are less prone to atmospheric attenuation, and less attenuated signals will require less power and smaller batteries.

Spread spectrum transmission (SST) technology is a relatively low cost method for achieving wireless communication [36]. SST was initially used for military applications which required a high level of accuracy, such as NASA space shuttle S-band communications link, and tracking and data relay with a satellite systems program. It uses a radio signal diffused over a broad band to avoid detection by unauthorized users and to overcome intentional jamming signals. Some of the advantages of using the SST are listed below [36]:

- ultra secure communication
- high immunity to interference
- no FCC license required
- error free transmission
- fast user response time
- transparent to user software

A second application was designed for the purpose of facilitating multiple access in which several users simultaneously share the same satellite repeater power and bandwidth. The basic idea of SST is to widen the bandwidth of a given signal (voice, data, video, etc.) prior to transmission, by a multiple that is typically 100 to 1000 times its original bandwidth. The SST signal can be successfully decoded even if the noise level exceeds the signal level [36]. Such spectrum spreading is normally used for one or more of the following applications: signal security, multiple access, interference rejection, anti-multipath, selective calling and identification, and navigation.

6.4 Technologies for User Interface

This section discusses the technologies for user interface. This section do not include the contemporary common interfaces such as televisions, telephones and fax. The purpose of this section is to bring out the relatively new technologies which can be applied to ITMS.

6.4.1 Natural Language Processing

In order for ITMS to gain wide acceptance it is important to utilize a user interface that is easy for people to use. The method of communication which people are most accustomed to is the use of natural language. The particular areas of natural language processing which are relevant to ITMS include speech synthesis, automatic speech recognition, and written natural language understanding. Although these topics may seem similar, the applications and requirements for each are somewhat different.

Speech synthesis. Speech synthesis generally refers to the capability of a computer to talk to the user. The two basic approaches to speech synthesis are copy synthesis and synthesis by rule. Copy synthesis utilizes a limited vocabulary of prerecorded words and phrases. The speech output is simply produced by combining appropriate words or phrases from the stored vocabulary. In a synthesis by rule system, speech consisting of any combination of spoken words can be generated. To do this, the computer uses rules that analyze the syntax and semantics of sentences in the form of written text and convert the sentences into spoken words that imitate the human voice [29].

Automatic speech recognition. Another category of natural language processing is automatic speech recognition. Automatic speech recognition refers to the ability of a computer to understand spoken language as an input and respond by performing a specific task. Speaker independent and speaker dependent are the two types of speech recognition. Speaker independent speech recognition allows a computer system to understand spoken words, regardless of the person, their accent, and dialect. However, this can only handle a speaker independent vocabulary of approximately 10 words [9]. On the other hand, a speaker dependent computer system can be trained to handle a larger vocabulary. The required training for such a system also enables it to cope with unusual speech patterns. The problem, however, is that it must be trained for each person.

In order for the computer to be able to translate everyday words and sentences, it must have the ability to understand phrase structure and the rules of grammar or syntax in addition to the meaning of words. The problems involved, however, are that the computer must simulate the thought process, the meaning, and simulate the world knowledge and context incorporated in the spoken input. Due to the difficulty in performing such tasks, many of the available speech recognition systems are designed to only handle isolated words from very limited vocabularies [9]. The additional difficulty encountered by continuous speech recognition systems results from the continuous nature of speech itself. In fluent speech, the end of one word tends to merge with the beginning of the next word without a distinct pause in between [24].

In both speech recognition approaches, contamination of the speech signal poses another problem. Background noises such as echoes, other voices, or traffic noise can all interfere with the recognizer's ability to interpret speech. When the speech signal is sent over a telephone line or radio link, distortion and delay cause further contamination [24].

Applications. In the past speech input/output has been used to aid people with disabilities. Used in conjunction with ITMS, speech processing can better enable the disabled to use public transportation thereby increasing their mobility and independence and improving their quality of life. To the extent that a person with a physical disability may not be able to manipulate the keyboard of an ITMS device, speech recognition would allow them to select an origin and destination and inquire about routing and schedules. In such a system the vocabulary and syntax should be carefully chosen in order to reduce errors. That is to say that the words used should be acoustically distinct, easy to say, and come readily to mind, while at the same time the grammar may be somewhat rigidly structured

[9].

Blind users could benefit from the implementation of both speech synthesis and speech recognition. The previously mentioned considerations for speech recognition would still apply in order to reduce errors that may occur in the noisy environment inherent to public transportation. Using speech synthesis could easily provide a blind person with information necessary to make a trip using public transportation. In conjunction with GPS the ITMS device could be triggered to provide information based on its location.The recommended route number, along with the names of the origin and destination and the corresponding arrival and departure times all meet criteria that justify the use of speech output. These criteria include the following conditions: that the message is short, simple, deals with events in time, and the user cannot utilize visual presentation [9].

Natural language understanding. For the general public speech processing may not provide a cost effective interface. However, natural language processing has been used to enable natural language input in the form of typed text to be interpreted by a computer for the purpose of performing desired tasks [2]. In such a system users would use the same natural language to ask the computer questions that they would use if they were asking a person directly. The user could also ask the computer to perform certain tasks without knowing specific terms or commands. Thus people without a lot of experience using computers could access information about a bus route by simply typing "Could I see a bus schedule for Route 5". The ability of the computer to interpret natural language inputs is only limited by the number of rewrite rules that specify the allowable grammar or syntax. Consequently, with more rewrite rules in the program, the computer can interpret a larger variety of natural language inputs.

Undoubtedly, as more research is done in the area of natural language processing and as technological advances are made in computers, quality improvements and reduced costs will allow natural language processing to fulfill needs that haven't been met by more conventional technologies.

6.4.2 Interactive Television

Interactive television is a television with computing capabilities [22]. ITV, as it is called, provides a means for the non-computer oriented to utilize the facilities of a computer through a black-box which interfaces the computer and the television. Several proponents of the ITV idea are convinced that people do not want to learn how to use a computer, preferring the familiarity of TV. One of the advantages of using this method of communication is that it is possible to reach out to the average household which is generally inclined towards using public transit.

For the purpose of transmitting information over the TV cable or an FM band (as a sub-carrier of an FM radio station) on a specially assigned band-width on the spectrum, it may be necessary to replace some of the existing cable with co-axial cables. Enhanced capacity (using twisted-pair cables) telephone based ITV is also an alternative for transferring data. A video dial tone would allow the user to send instructions about what he wants to see. Thus, the signals from the central information processor will be sent to the cable TV office through wireless transmission which will pass on the modulated signals to the modem device at the user's TV. The black box attached to the television will provide computational ability to the TV. For sending signals back to the central information processor, the user will have to use a low-power transmitter and a modem device. Today's ITV service operators provide services such as news, weather forecasts, and other community related information.

6.4.3 Personal Computer (Desk-Top Computer)

The desk-top personal computer (PC) is a most popular method to access information stored either in the PC or used in the main frame using it as a terminal. In the initial phase of ITMS development PC will be the most appropriate device because it is widely available and the user are familiar with how to operate it. PCs interface with the mainframe computer via telephone lines or a dedicated computer network.

6.4.4 Hand-Held Computer

Significant advances have been made in the development of hand-held personal computers in the recent years. The latest trend in hand-held computers has been the development of a personal digital assistants (PDAs). PDAs come in a variety of configurations capable of performing communication, compression, handwriting recognition, as well as other custom functions [30]. Some of the latest hand-held computers such as Envoy, by Motorola have integrated wired and wireless communications capabilities supporting cellular phone, fax, and electronic-mail [28].

The hand-held computer will represent the ultimate stage of the ITMS user interface. The device is portable and small enough to fit in a coat pocket. The device can store information and perform minor computations, and also it can be used as a terminal when connected to the central processor to obtain the real time information and itinerary preparation. The connection may be made at public telephones or possibly at bus or train stations where computer hook-ups are installed.

Limitations. At present, the cost of these systems is rather high. Hand-held computers without wireless communication generally cost around $500, and to add wireless capability can cost another $500. Systems with integrated wireless communication can cost over $1500. Another drawback to current systems is a lack of memory. Many systems now available only have 1MB of RAM, which is not sufficient to run complex algorithms or store large databases. Low power operation processors are being developed for hand-held computers to extend battery life, however communications modems still can cause a significant reduction in operating time [12].

Chapter 7

ALGORITHMS OF DECISION-AID SYSTEM

This chapter discusses the structure of the algorithms which prepare feasible travel itineraries and then select the best one among them. Two algorithms are presented in this chapter: one that develops feasible itineraries given the planned activities within a time period; and the other that ranks the itineraries according to the degree of match with the traveler's requirements. An important requirement of the decision-aid algorithms is their ability to emulate the decision patterns of individual travelers.

7.1 An Algorithm for Itinerary Preparation

This algorithm prepares the itinerary for the traveler given a set of planned activities in a time period. When this task is done by human beings, it involves organizing the sequence of the activities according to the available transit service in order to allow the person to complete all the activities by transit. The decision-aid algorithm presented in this section compares the requirements of individual activities and the availability of transit services and organizes the sequence of activities so that transit can be used to travel to the activity sites.

The necessary information (or data) to execute this algorithm is:

- available transit service (timetable and fare),
- the traveler's desired activities (including desired arrival time, duration of each activity, desired departure time, and the precedence relation among the activities (the sequence of the visits)).

The match between the available transit service and the traveler's desired times at each trip leg determines the feasibility of an itinerary.

The following presents the basic structure of the algorithm followed by the explanation of the notation.

7.1.1 Notation

- δ_i: the minimum dwell time at location **i**, or the amount of time the person wishes to spend at location **i**.

- $\mathbf{ET_i}$: the earliest desired arrival time at location **i**.
- $\mathbf{LT_i}$: the latest desired departure time from location **i**.
- $\mathbf{t_{ij}}$: travel time from location **i** to location **j**.

Note that the **i, j** pairs falling on the planned route only have a precedence relation, that is, $\mathbf{ET_i} < \mathbf{ET_j}$.

7.1.2 Itinerary Development

It is assumed that a person plans several activities in a time period, for example, a visit to the doctor's clinic, shopping at a mall, and shopping for groceries before returning home after a day's work. It is also assumed that the person knows the dwell time (the amount of time he wants to spend at each location) in approximation. These assumptions represent the prior knowledge that the traveler has while planning a set of activities.

Consider the scenario in which a person wishes to visit five locations starting from and ending at home. The set **I** represents a set of origins and destinations:

$$\mathbf{I} = \{1, 2, 3, 4, 5, 6, 7\}$$

where, **i**=1 and **i**=7 refer to the starting and ending points respectively, which, in this case, are both home. **i** = 2,3,4,5,6 are the locations that traveler wants to visit.

Let us also assume that the earliest desired arrival time at i,$\mathbf{ET_i}$, and the latest desired departure time at i, $\mathbf{LT_i}$, are provided for **i**=1, **i**=3, **i**=5 and **i**=7. We define two more sets, **K** and **L,** for a set of locations where the earliest desired arrival and latest desired departure times are known, and a set of locations where the desired arrival and departure times are not known, respectively. In other words,

$\mathbf{K} = \{ \mathbf{i} \mid \mathbf{ET_i}$ and $\mathbf{LT_i}$ are given $\}$, in this case, $\mathbf{K} = \{ 1, 3, 5, 7 \}$.

$\mathbf{L} = \{ \mathbf{j} \mid \mathbf{ET_j}$ and $\mathbf{LT_j}$ are not given $\}$, in this case, $\mathbf{L} = \{ 2, 4, 6 \}$

The task of the algorithm is to insert the locations from set **L** between location from set **K** such that all of them can be visited by the available transit services.

Figure 7.1 illustrates the sequence of visits; the horizontal line represents the time and the square dots indicate the specified arrival and departure times (elements of set **K**). The length of the group of square dots indicates the duration of possible stay at each location. The task is to insert the locations with unspecified arrival times (elements of set

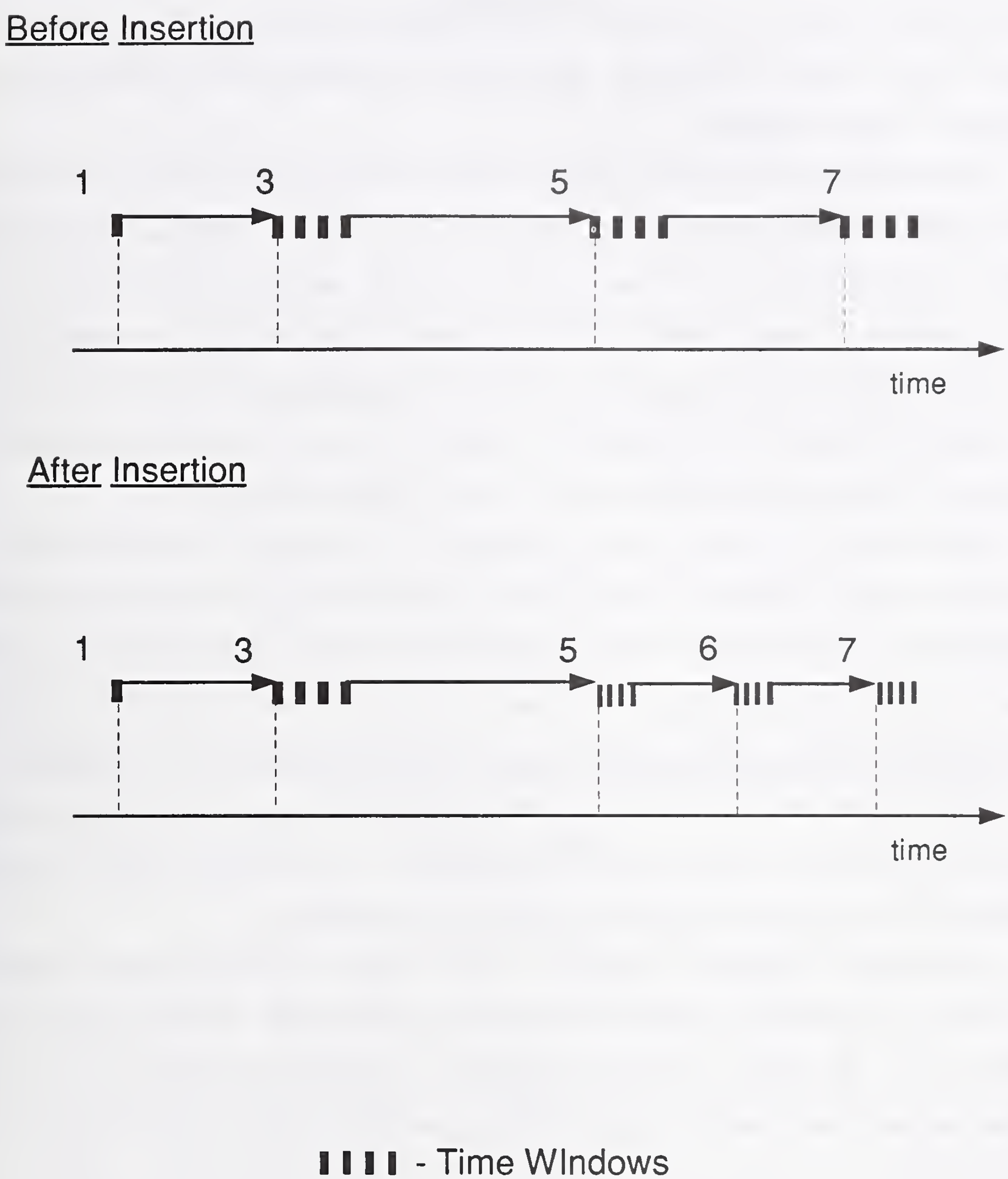

Figure 7.1 Sequence of visits before and after insertion

L) between the square dots (locations with specified arrival and departure times) in such a manner that visits to all locations (all elements of **K** and **L**) are possible within the constraints of transit schedule.

The determination of the trip sequence uses a trip feasibility matrix which indicates the precedence relation among the arrival times. This matrix is developed by checking the feasibility of travel between locations. Table 7.1 shows the trip feasibility matrix for our example problem. A value 1 indicates that the travel is possible from i to j, corresponding to the origin (row) and the destination (column). For instance, location 5 is to be visited after location 3, therefore, it is impossible to make a trip from location 5 to location 3; thus the element of the fifth row and the third column of this matrix is 0.

The elements of the matrix represent the feasibility of trips between the corresponding pair of locations; zero (0) indicates that the trip is not feasible, and one (1) indicates that the trip is feasible. As represented in the matrix, trips to and from locations 2,4 and 6 are possible depending on the time at which the traveler decides to visit them. Thus, trips such as those between locations 1 (3, 5 or 7) and 2 (4 or 6) are feasible.

The locations indicated as free locations (belonging to set L) for which the times of visit are not fixed, can be inserted into the current tour. An algorithm called the Insertion Algorithm [19] can be used to test the conditions for insertion.

The insertion algorithm mentioned above follows a two step process: building an initial route, and insertion of additional trips into the initial route. When inserting trips into the initial route, the model checks the feasibility of insertion for each trip first; then, it identifies the maximum number of trips which can be inserted using a tree structured search technique [19].

It is also assumed that the person knows the earliest arrival and the latest departure times at any location belonging to set K. It is also assumed that the time that elapses between the earliest arrival and latest departure times at any location includes the minimum dwell time at the location. Thus, mathematically,

$$LT_i - ET_i = \delta_i + \text{SLACK TIME} = \text{time window}$$

The slack time at any location helps model the uncertainty of the traveler with regard to the time range. Such uncertainty exists as the person making the decision has incomplete

Table 7.1 Initial Precedence Matrix

ORIGIN \ DESTINATION	1	2	3	4	5	6	7
1	0	1	1	1	0	1	0
2	0	0	1	1	1	1	1
3	0	1	0	1	1	1	0
4	0	1	1	0	1	1	1
5	0	1	0	1	0	1	1
6	0	1	1	1	1	0	1
7	0	0	0	0	0	0	0

Table 7.2 Precedence Matrix After Applying Insertion Algorithm

ORIGIN \ DESTINATION	1	2	3	4	5	6	7
1	0	1	1	1	0	1	0
2	0	0	1	1	1	1	0
3	0	1	0	1	1	1	0
4	0	1	1	0	1	1	1
5	0	0	0	1	0	0	1
6	0	1	1	1	1	0	0
7	0	0	0	0	0	0	0

knowledge about the scope of future events; the availability of slack time is essential for successfully applying the insertion algorithm. It is the time window which allows other stops to be inserted in the existing schedule.

Having defined the concept of time-windows, the insertion algorithm is applied to the hypothetical case. Using the notation presented above, let us consider that a location **j** (from set **L**) is being evaluated for insertion between the locations **i** and **i+1** (from set **K**). The following checks are performed for the evaluation.

1. Condition of insertion. The transit vehicle is able to travel from **i** to **j** and, from **j** to **i+1** without violating the time constraints at **i**, **j**, and **i+1**.
2. Adjustment of time-window size. Insertion of location **j** and subsequent changes in time-window of locations **i** and **i+1**, influences the availability of time-windows at all other stops. Thus, all the time-windows must be checked and their size must be adjusted. If a time-window of a previously assigned (belonging to set **K**) location is not available, location **j** will not be inserted.

Refer to Figure 7.2 for an illustration of the adjustment of time windows because of the insertion of location **j** between locations **i** and **i+1**. As noticed, as a result of inserting location **j**, the sizes of time-windows for those before and after i and i+1 respectively, are reduced. As more locations are inserted, the time windows eventually reduce to zero.

Based on this method, the locations of set **L** are sequentially inserted as long as time-windows at the locations permit. Suppose that the insertion algorithm is used to insert location 6 among the locations 1-3-5-7, and that the algorithm inserts the location 6 between the locations 5 and 7. The new precedence matrix which will be used for inserting the remaining locations from set **L** is illustrated in Table 7.2. Again refer to Figure 7.1 for an illustration of the itinerary after this iteration of the insertion algorithm. As is apparent from the figure, the location 6 is inserted between the locations 5 and 7.

As an example, the insertion algorithm might result in the following itineraries:

1. 1-3-2-5-6-4-7
2. 1-2-3-4-5-6-7
3. 1-3-4-5-6-2-7

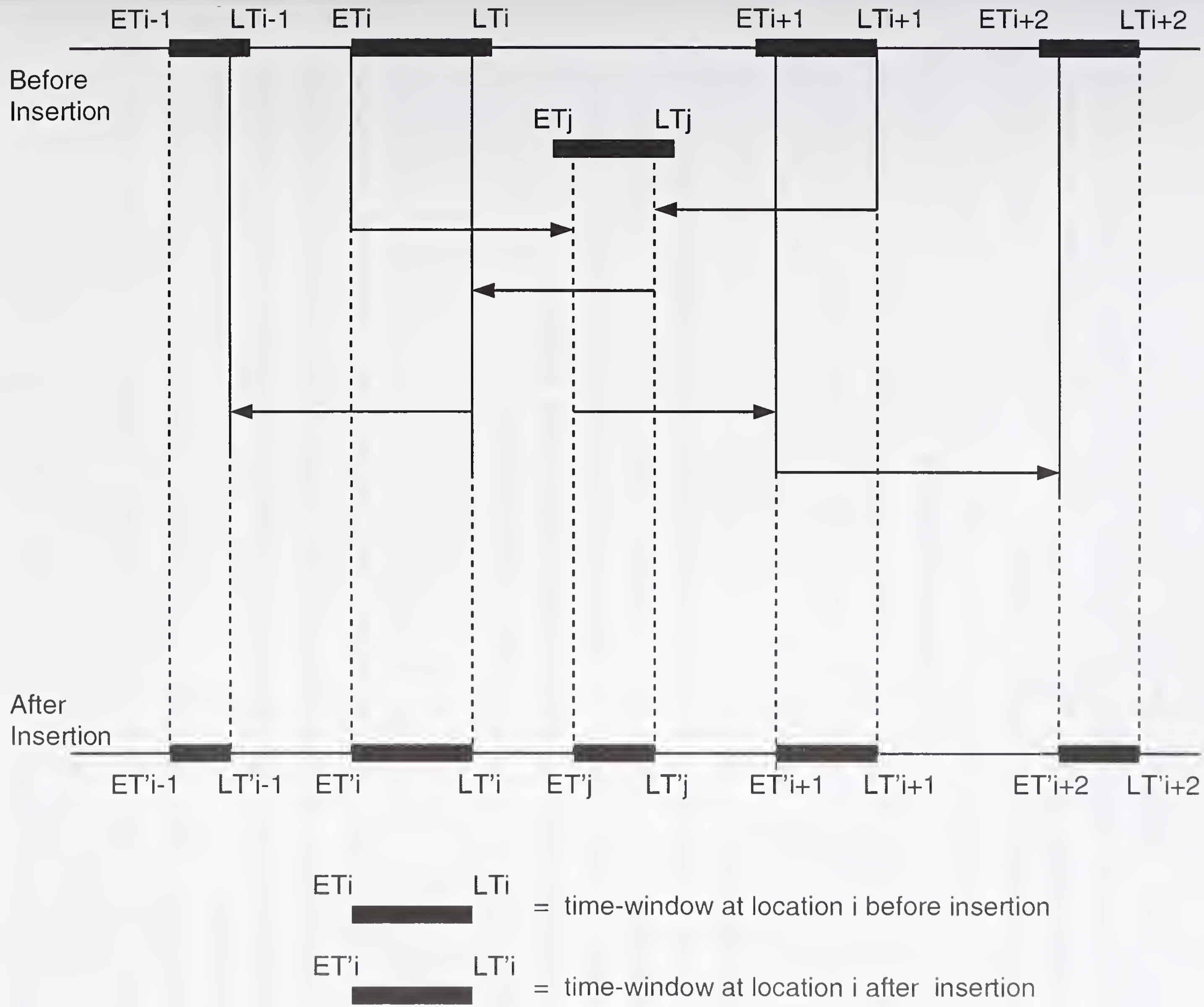

Figure 7.2 Adjustment of time-windows

4. 1-2-4-3-5-6-7

In this example, all other permutations have been found as infeasible and will not be further considered. The next task is to rank these four itineraries in an order that best matches the requirements of the traveler. The next section presents a method for ranking the itineraries generated by the insertion algorithm.

7.2 Schedule Evaluation

When more than one alternative itineraries are developed, then it is necessary to rank them in the order that matches the traveler's desire and requirements. The ranking should be consistent with individual traveler's preference in terms of the number of transfers, waiting time, stop locations, total cost, feeling of security, etc. Ranking of itineraries is not an easy task. This section discusses how to rank itineraries under this decision environment.

A method to rank itineraries should satisfy the following requirements:

- Ability to emulate the decision making process of the traveler,
- Simplicity of adapting to a computer based algorithm.

Several methods for ranking alternatives were evaluated; among those considered were fuzzy integral and clustering techniques. Based on the criteria mentioned above, the method of fuzzy integral was considered suitable for evaluating several itineraries. The following gives a brief introduction to the application of the fuzzy integral method to ranking alternatives.

Consider that several alternatives exist and they are evaluated by their performance in satisfying several criteria. Based on the combined performance the alternatives are to be ranked. The traditional approach is to rank them according to the expected values of the performance. In other words, each alternative's performance with respect individual criterion are scored and the score is multiplied by the weight of the criterion. The sum of the product for all the criteria is considered the index for the alternative. The alternatives are ranked according to the values of the points.

Two problems exist in applying this expected value approach; first, the performance of an alternative with respect to each criterion is measured only subjectively; second, the criteria are not independent of one another, rather they are related. When one criterion is satisfied another criterion is partially satisfied. For example, the criteria for comfort and the absence of transfer are related, such that when one is satisfied then the other is satisfied to some extent.

The fuzzy integral method considers the weights of the individual criteria as the fuzzy measure. The fuzzy measure is a measure which satisfies only monotonicity and not necessarily the adaptivity requirements of the measure. In other words, the weights based on fuzzy measure do not add up to one as in the case of independent criteria, because the criteria are of non-independent and compensatory nature.

Let us consider the model which evaluates alternative itineraries. The attributes of the itineraries that will be evaluated are, x_1 = length of travel, x_2 = total travel time, x_3 = total money cost, x_4 = total number of transfers along the route, x_5 = comfort and safety of travel.

For a given itinerary, the performance regarding each criterion is scored by a number between 0 and 1. This score can be determined by subjective judgement or based on an established formula. For example, because the meaning of the acceptable total travel time (x2) is not clearly known, a fuzzy set of "acceptable travel time" can be created and the match between the expected travel time of the itinerary and the fuzzy set of "acceptable travel time" is determined. The degree of the match can be found by applying a fuzzy set operator (the reader is advised to refer to one of many textbooks on fuzzy set theory, for example, Zimmermann).

The weights of individual criteria are determined only as a cumulative value. The reason is because the individual criteria are interrelated so that addition of weights for two criteria does not necessarily represent the weight when the two criteria are combined. However, the value of the weight when the two criteria are combined will be at least greater than the original values of the individual weight; furthermore the value of the weight when all the criteria are combined should be one. This type of weight falls in the category of fuzzy measure, which satisfies only the monotonicity requirement.

Given the scores of performance for individual criteria and the non-additive values of the weights of the criteria, the overall performance of an alternative is calculated by the method illustrated in Figure 7.3. Given an alternative, the x-axis in the figure shows the criteria and they are placed in such a manner that the performance of the alternative with respect to each criterion is ranked in a decreasing order as shown by the decreasing line. The increasing line represents the cumulative weight as more and more criteria are combined. The maximum value of the cumulative weight is one.

The y-axis reading of the intersection of the two lines (one descending and the other ascending) represents the overall score of the alternative. For each alternative, the same procedure is repeated and the overall score of the individual alternatives are ranked to determine the final ranking of the alternatives.

Mathematically, the intersection of the two lines is represented by

$$\int h(x) . g = \max_i [h(x_i) \wedge g(H_i)]$$

where,

$$H_i = \{x_1, x_2, \ldots . x_n\}$$

$X = \{x_1, x_2, x_3, x_4, x_5\}$ represents the set of attributes for all the itineraries. Let there be ***m*** number of itineraries and let $h_j : X \rightarrow [0,1]$ be the function that expresses the evaluation value of the attributes of the *j* the itinerary. For example, $h_j(x_1)$ is the length of travel standardized within the interval [0,1], and $h_j(x_5)$ is the comfort and safety of travel quantified to a value between 0 and 1. Let the fuzzy measure *g* be the degree of consideration of an attribute during the evaluation process. For example, $g\{x_1\}$ is the degree to which the person considers the length of travel, and $g\{x_3,x_4\}$ represents the degree to which the person considers the total money cost and the total number of transfers along the route. As the degree of consideration gets larger when the number of attributes increase, *g* is a fuzzy measure [32].

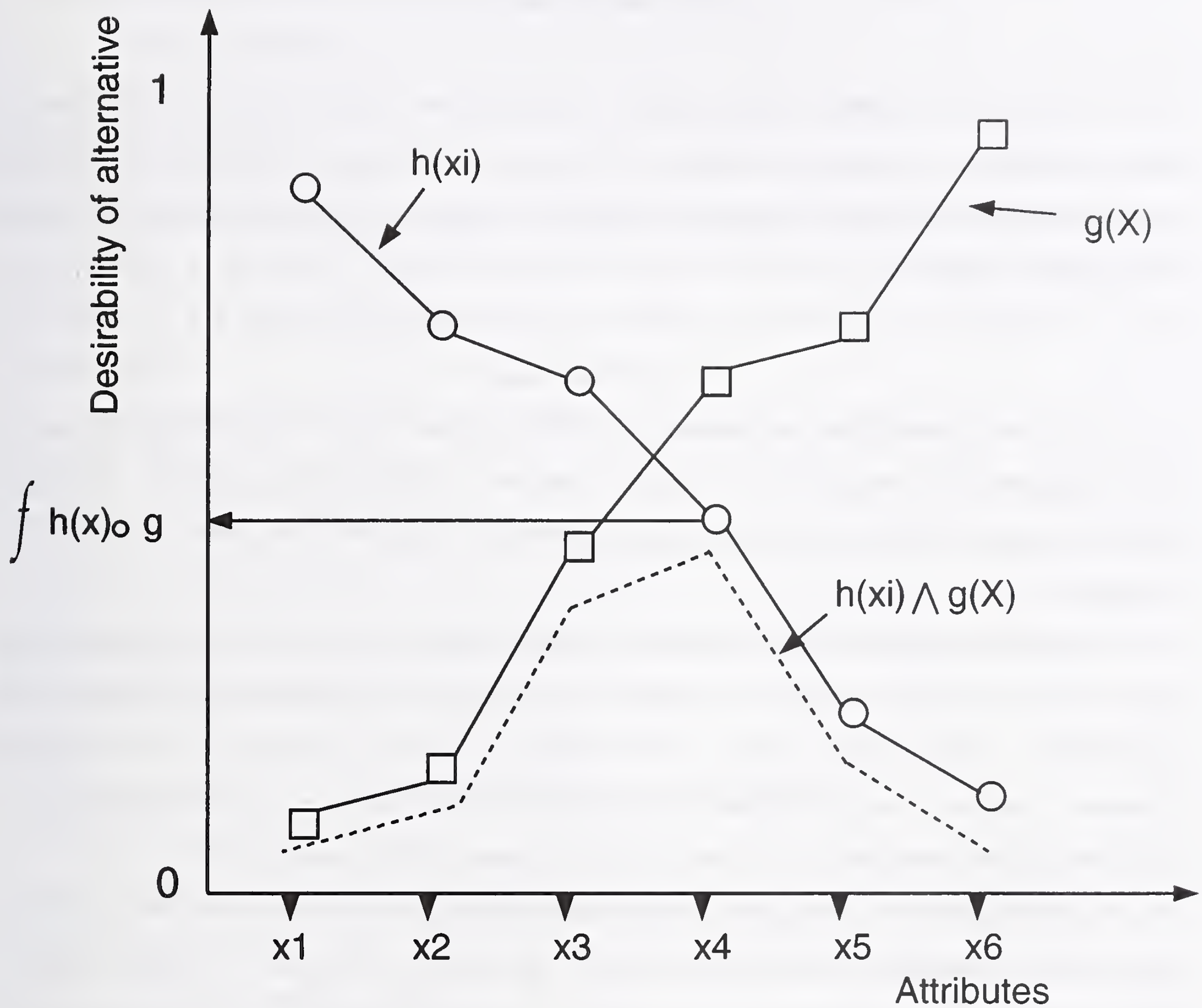

Figure 7.3 Calculation of the Fuzzy Integral

Chapter 8

IMPLEMENTATION

This section examines issues related to management, roles of different participants and implementation strategies. Because it is difficult to conduct a quantitative analysis without reliable information about the future technology, our discussion will be limited to the qualitative issues.

8.1 Management

Who will manage the operations of ITMS is an issue which affects many aspects of ITMS implementation including cost, effectiveness and efficiency. Organizations which can possibly manage ITMS are the transit agency, the city or state DOT, or a contracted private company.

The transit agency has a direct interest and an inherent incentive to manage ITMS because of the ITMS's potential to increase the ridership and improve the image of the organization. Information regarding the schedule, fare, and operating status is readily obtainable internally, and the agency's knowledge about the service and the characteristics of the riders can make the ITMS sensitive to the needs of the users.

The drawbacks of having the transit agency manage ITMS, however, are: (1) a new section which manages ITMS must be created; the section will operate a large computer system, manage data, and handle user interface. Because ITMS will not be the traditional function of a transit agency, an extensive reorganization, along with new sections of electronics, data management, and interagency coordination will be needed; (2) coordination with other transportation agencies in the region will be required, including city and state DOTs (particularly those dealing with ITS), other transit agencies (both public and private) and the police. ITMS should be an integral part of a transportation information system in the region. This purpose may not be fully achieved if the transit agency manages ITMS.

Contracting a private company at the state or city government level is another possible arrangement to manage ITMS. This arrangement can create incentives to make the system work efficiently at lower cost theoretically. It is, however, questionable whether or not a private sector company will indeed undertake a project such as ITMS, which initially involves high risks regarding profitability and social responsibility.

A third and perhaps the most logical position from which to manage ITMS is the city or state DOT because these organizations have the overall responsibility of transportation service (both highway and transit) in the region. Considering the need for integrating ITS and ITMS, public sector management will have a better mechanism for sharing data and communications channels. However, the advantage of having the first hand knowledge and information on transit operation may not be available as in the case of management by the transit agency.

One aspect which will be critical to the management of ITMS is the operation of the computer system. Management of data obtained from GPS and GIS as well as that pertaining to transit services is a significant task. Moreover, preparation of itineraries for individual users simultaneously in the real time environment requires massive computational facilities. Hence, the question of which agency will manage ITMS must be evaluated in light of the most efficient and reliable computer management.

8.2 Role of Different Participants

The participants interested in and affected by the operation of ITMS are: the traveler, transit agencies, private industry (automotive and electronic industries), and the society in general. Given below is a brief discussion on issues relate to each participant.

8.2.1 The Traveler (ITMS User)

The traveler will benefit from ITMS due to increased mobility and savings in time, and above all, reduced anxiety when using public transit. The traveler, however, must initially make an effort to understand the ITMS procedure. During the development of ITMS, the public should be an active participant in the performance monitoring process as they will be most affected by the features and performance of ITMS.

Two groups among the users, captive rider and choice riders will have different interests in the features of ITMS. The captive riders will be interested in the real time information (e.g. seat availability, on-time status,etc.) since they are already familiar with the basic information about the transit service. The choice riders, on the other hand, will be interested in the basic information of transit system (e.g. stop locations, route, and fare,etc.) as well as the real time information. The performance of ITMS should be continuously monitored by the users.

8.2.2 Transit Agencies

ITMS will represent a totally new mode of management and operations to a transit agency. Under ITMS a transit agency is no longer just a transportation service provider but a transportation information provider as well. The user will be monitoring closely not only the service performance but also the performance of ITMS. Hence, a significant changes in the management philosophy must take place and the changes must be reflected in the organization and hiring of the employees.

ITMS requires coordination and cooperation among the transit agencies in the region including providers of specialized transportation for disabled persons, long distance bus companies, and possibly AMTRAK. Significant preparation will be needed to coordinate the information exchange among these agencies.

8.2.3 Private Industry

The private sector will play a major role in ITMS in the development of communications, vehicle detection technologies, and software; development and manufacturing of the user interface device; development and possibly contracted computer operations. While the market potential is great, the perceived initial risk will also be large unless the private sector participates in the ITMS development process from the beginning and understands the experimental nature of the development. Studies on ITMS market must be performed to assess the market potential and profitability.

It is believed that the concept of ITMS can gain acceptance in many cities in the world. Considering the greater transit usage in cities of industrialized nations, in particular, those in Europe and Asia, the market potential for ITMS is more plausible in foreign countries than in U.S. cities initially.

8.2.4 Society

The societal benefits of ITMS are many. Greater transit ridership and inevitable improvement of transit service will help regain the quality of mobility in the city. Information has long been neglected as a vital element of transit service. Perhaps the greatest benefit that information will bring about is the lessening of anxiety associated with using public transportation. The feeling of having ready access to information reduces one's major resistance when one is contemplating to use transit.

Along with the benefits, the society must expect to face new issues and problems which are common when any major public system is implemented. Potential legal implications due to the failure of the system must be expected. Consequences of failing to predict the arrival time accurately, for example, may result in litigations by the affected, and possible media outcry leading to the question of justification of future funding.

Because the cost of implementing and operating ITMS will be significant, allocation of funds between the traditional transit operations (vehicle operation and service) versus the ITMS operations must consider equity among the beneficiaries of the services. As the greatest benefit of ITMS will be enjoyed by the choice users and those who rarely used transit before, the issue of equity in funding ITMS will probably arise. Also, the benefits derived from ITMS may not be perceived uniformly among the users.

8.2.5 Governments

During planning, development, implementation and operation of ITMS, state and federal governments must be the principal overseer of the processes. The role of the government will be to set up a mechanism to ensure the smooth coordination among different agencies, to facilitate the transfer of technology among cities, and to promote uniformity of the systems in terms of features and user interface methods.

The FTA needs to develop guidelines for development of ITMS with regard to the responsibilities of related parties: transit agencies, local planning agencies and government, and manufacturers of ITMS equipment regarding the uniformity of the systems and the technology exchange process.

Local transit agencies should develop a long range plan for improving information dissemination to the public. ITMS should be an element of the long range information improvement plan. Perhaps, an annual element of the plan can include individual tasks geared toward implementation of ITMS.

Local and state governments must consider ITMS as an integrated element of the transportation improvement plan along with ITS. The framework of coordination among agencies such as, the police, traffic departments, transit agencies, MPO, and weather service, must be developed. Because the major part of the coordination pertains to data acquisition and exchange, the policy of cost sharing is another important matter to be addressed.

To facilitate private sector development of products required for ITMS, the FTA should outline the scope of ITMS in terms of technology required, marketability and the long range commitment so that the manufacturers can examine the technology development needs and investment returns.

8.3 Implementation Schedule

This section presents the sequence in which the ITMS development activities should take place over the next decade. The proposed ITMS development process is categorized into four phases, each phase is characterized by the features of: type of data used, type of information delivered, system software type, and method of user interface. The phases are separated according to the predicted sophistication of technology and computer software requirements. User acceptability will play a major role in verifying the transition from one phase to the next.

The following four phases should be executed sequentially with each new phase preceded by an extensive evaluation of the previous phase by the users. The four phases are also illustrated in Figure 8.1.

Phase 1 - Data stored in the central computer: general schedule
- Information to be delivered to the user: static information one-way communication
- Medium of user interface: stationary

Phase 2 - Data stored in the central computer: general and real time
- Information to be delivered to the user: real time, one way communication
- Medium of user interface: stationary

Phase 3 - Data stored in the central computer: general and real time
- Information to be delivered to the user: real time user interactive
- Medium of user interface: stationary

Phase 4 - Data type in the central processor: general and real time
- Information to be delivered: real time and user interactive (e.g. itinerary)

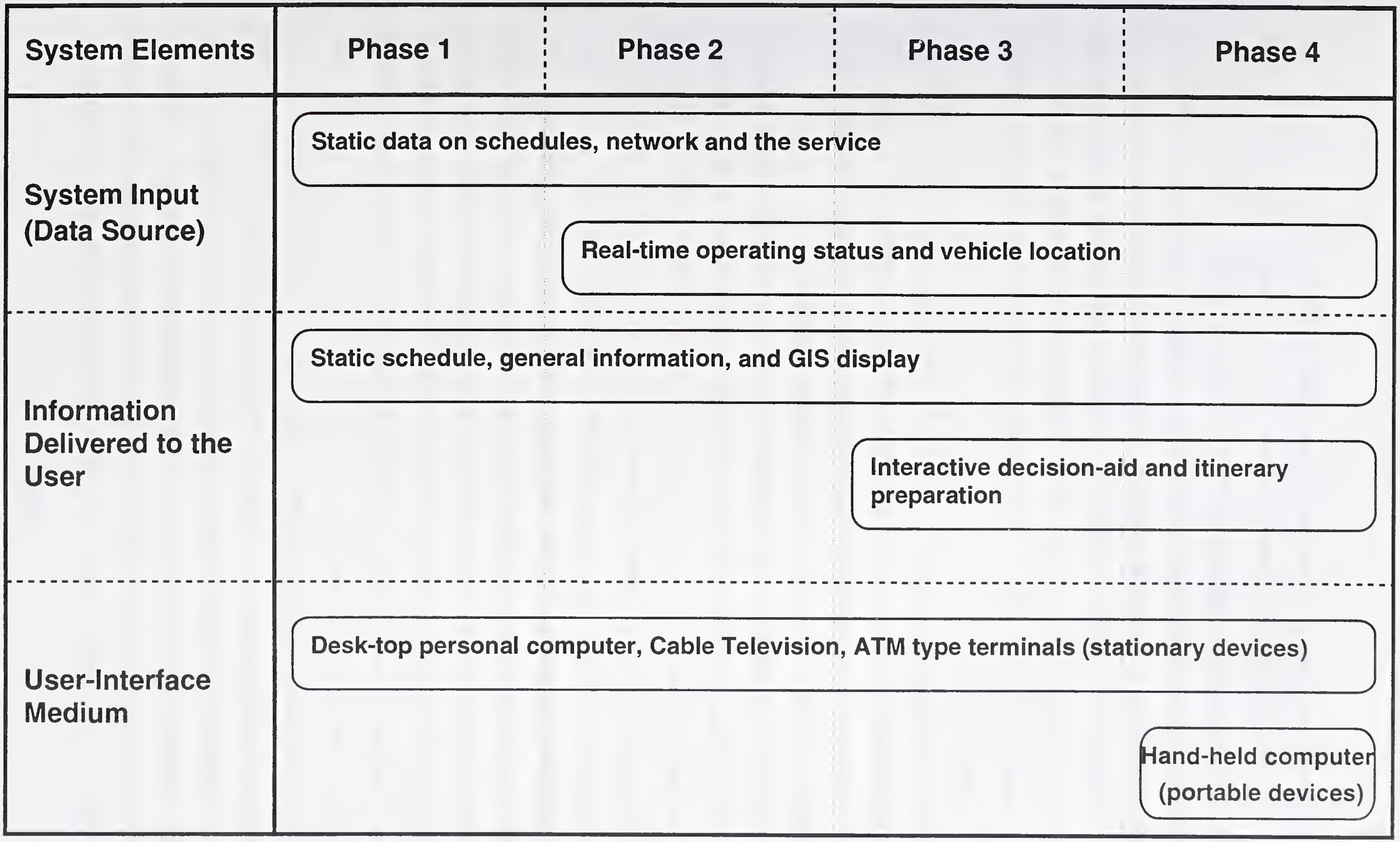

Figure 8.1 ITMS Development Phases

- Medium of user interface: stationary and portable device

Phase 1 is characterized by allowing the user to access transit information via the existing computer terminals or a dedicated channel of cable TV. This is a change from the traditional mode of information delivery, which has been through the printed schedules and, in some cases, through the wall posted schedules. In this phase, the user can obtain only pre-packaged information on routes, schedule, fare, general information about the system, stop location, etc. The products in this phase will not allow the user to ask specific questions and interact with the computer, except for the route and timetable when an origin and destination pair is given.

This phase still represents a great leap in the dissemination of information from the traditional information delivery mode. The transit agency can quickly (near real time) "broadcast" any changes in the schedule, such as detours, weather related changes, delays, via the computer information network or cable television channel.

The most likely beneficiaries in this phase will be those users who have access to computers in their offices. The office PC can be connected to the transit agency's computer using the computer communications network. In addition to PCs, ATM type transit information access device can be located in major stations and public places. (this idea has already been tested in several cities, e.g. Houston and Yokohama).

Phase 2 involves upgrading the data used in the system to real time operations data, while the other aspects of the system remain the same as in Phase 1. To implement Phase 2 two issues must be resolved; one, technology for collecting vehicle location data in real time, and two, organizational arrangements for the collection and management of the data. The technical problem of data collection is discussed in section 6.1 and the organizational aspect is discussed earlier in this chapter.

Assuming that these problems in Phase 2 are solved, the user will receive the real time information regarding vehicle on-time status, seat availability, space availability at Park and Ride lots through the computer network and cable TV. With the appropriate software, the predicted vehicle arrival times at stops can be disseminated to the user. While the information that the user receives will still be limited to certain packages, the quality of information that a user receives, however, will be significantly enhanced. The information will be similar to the one that an air traveller receives at an airports as to the schedule and on-time status of aircraft.

Phase 3 incorporates the computer software which can perform various user specified instructions, for example, itineraries development, estimating the arrival time after more than one transfer. The algorithms will find the best route between two points and will rank the alternative paths given the real time operating information.

Two possibilities are considered with respect to the way the algorithms become available to the user. One, through the main frame computer, and the other, the PC based programs. In the former, the main frame computer will perform all the functions for all the users and the PC will act merely as a terminal. In the latter case, a set of itinerary building programs may be sold and the individual users will develop itineraries given the real time data delivered to the PC from the central computer via e-mail.

Phase 4 is the final stage of the ITMS development. In this phase the use of user interface device will be much more extensive than in the previous phases. In addition to the desk-top PC and cable TV, the information can be obtained by the hand-held computer as discussed in section 6.4. This feature allows access to real time information not only from office and home, but also on street and in the car. A most prominent feature of this phase is the use of hand-held computer as the user interface.

The hand-held computer can be plugged into any public telephone or cellular phone to retrieve real time information and also to obtain answers to specific questions. A person having the hand held device traveling to a new city, can obtain transit information for the city by plugging the computer into a public phone to retrieve information, provided that the data format is standardized. In order to allow such scheme, telephone companies will participate in the information dissemination business.

Another advanced user interface is a voice based portable device which can be carried either by hand or placed in a car. The following situation can be realized. The device is placed in a car and as the driver approaches a park-and-ride lot of a train station, availability of parking spaces, arrival time of the next train and the expected arrival time at the destination station can be presented to the driver by voice and the driver can then carry the device after parking the car.

The introduction of each phase must be carefully scheduled so that user satisfaction and system reliability are attained in each phase. Unless the system exhibits usefulness and a very high level of reliability, it will not be attractive to the public,and hence will not serve the original purpose of attracting transit ridership. Any such novel system needs time to attain a reliable performance; hence, a gradual transition from the current system to the interactive personalized system proposed in this project will aid in general acceptance of the system.

Chapter 9

CONCLUSIONS

This chapter concludes the presentation of this report by summarizing the mission of ITMS, limitations and difficulties of its implementation, and the future research needs.

9.1 Mission of ITMS

The mission of ITMS is to make public transit accessible to the urban travelers by providing relevant information which facilitates the travel decision making process. Many of its features are designed to target the choice or first time transit users. The ultimate purpose of the ITMS development is to make transit travel a routine choice of the general public; in other words, checking the availability of transit service before using the automobile becomes a routine practice of most urban population.

Benefits derived from ITMS will be different for the captive transit users and the choice transit users. The captive users will benefit the most by the availability of real time information; in particular, if the real time information is obtained through a portable user interface device. The choice user, on the other hand, will benefit by ITMS's ability to obtain transit information at any moment; both the general information and personalized itineraries of the trips. ITMS will bring about changes in attitude toward selecting transit for most urban population; less anxiety before and during travel by transit and greater productivity realized by accurate planning of daily activities.

Because the public will be monitoring the operating performance of the transit system through ITMS constantly, the transit agency will have sufficient incentives to maintain better service and reliability. Further, ITMS will allow the transit agency to dynamically control its operations, for example, in order to respond to a sudden surge of demand (which can be monitored in real time), temporary changes in the schedules can be instituted and they can be quickly disseminated to the public.

In addition, ITMS will offer the electronics and computer software industries an opportunity to develop and market products related to the user interface and the system operations. In view of the developments already taking place in Europe and Japan. In intense overseas market competition is expected for the ITMS products.

9.2 Limitations of ITMS

While the purpose of ITMS is to improve the decision making process of the travelers who are contemplating to use transit, the ultimate goal of urban public transportation is to provide mobility and promote better balance in the use of urban transportation modes. Promotion of public transit is based on the premise that the automobile cannot function as the sole provider of mobility in the urban area. From the physical standpoint, collecting travelers at limited locations and time periods and transporting them as a mass, as opposed to the case of each traveler driving his/her own vehicle, is much more efficient in terms of land use, energy use, environmental effects and creation of better living space. From the societal standpoint, public transport is an integral element of the basic responsibility that the society must offer.

Unlike the automobile, the performance of transit improves with greater ridership; in other words, the greater the ridership, the greater the possibility to improve transit service, this is not the case of the automobile mode. At the same time, transit service degenerates as the ridership decreases. Hence, making the transit travel attractive and anxiety free is the central issue in transit planning.

ITMS facilitates decision making in urban travel, this alone will not attract the public to transit. Regardless of the availability of information, the transit service must be acceptable to the public in terms of frequency, area coverage, schedule coordination, reliability, safety and security. Therefore, ITMS implementation must be paralleled with and preceded by the improvement of the existing transit service.

9.3 Implementation Issues

Many problems lie ahead of the implementation of ITMS. They are technical, financial and institutional. Technically, technologies of the four main components (collection of operating status, communications, central processor and user interface) must be developed to proven reliability. The technical developments of these elements must be coordinated with those of ongoing ITS effort as most of technologies are common between the two. From the financial standpoint, costs for initial development and operations must be assessed; and at the same time they must be checked with the effectiveness in attracting ridership and market penetration. From the institutional standpoint, the largest problem is how to define the role of the related agencies and to coordinate them: in particular, transit agencies, highway departments, the police, the planning agency, and the FTA. The mechanism for cost sharing among the agencies and user charges must be developed. Furthermore coordination among cities will be required for standardization of data format and software. In solving many of these problems, it is very important that the effort for the ITS and ITMS developments be coordinated. The objectives of ITS and ITMS must be complementary.

It should be noted that, regardless how much of the ITMS schemes materialize, transit agencies must provide as much user sensitive and friendly information as possible to the public. As discussed in Chapter 8, the development of ITMS will be gradual and a complete understanding of information needs must be established before any scheme of information delivery is implemented.

9.4 Future Research Issues

The future research agenda related to the ITMS development include the following:

Examination of how to integrate the development of ITMS and ITS projects, including how to coordinate the technology development and how to manage the operations, and information collection of the two systems.

Cost and benefits analyses of ITMS must be performed under different scenarios in terms of the size of transit systems, ridership potential, and service performance. Such analysis helps identify the financial risks, subsidy level and the budget justification. Furthermore this information is useful for the private sector to assess the profitability of technology development ventures.

A demonstration project of ITMS should be performed for a medium sized city. The demonstration project will provide the basis for assessing the cost, technical and operational difficulties, and the degree of coordination among agencies.

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APPENDIX

SURVEY OF TRANSIT USER DECISION PROCESS

This survey is being conducted as a part of a research project for the Federal Transit Administration to evaluate the feasibility of a portable decision-aid system for transit users. The decision-aid system will provide users with transit information.

There are six items in this survey. Each item describes a situation, and then lists several questions you might ask in the given situation. Grade the importance of having the answers to these questions. Please indicate the grade by circling the appropriate number next to each of the questions.

SITUATION 1

You are at the airport in Seattle. You want to go to your hotel by some mode of public transportation.

The decision aid system will provide you with the answers to the questions below. Grade the importance of having the answers to these questions when you are in the situation described above.

Grade 2 is least important

Grade 9 is most important

1. When does the next bus leave? 2 3 4 5 6 7 8 9
2. When does the bus reach the hotel? 2 3 4 5 6 7 8 9
3. Is the bus stop far from the hotel? 2 3 4 5 6 7 8 9
4. Is there a return bus to the airport? 2 3 4 5 6 7 8 9
5. Do I have a transfer? 2 3 4 5 6 7 8 9
6. If so, how long do I have to wait to take the connecting bus? 2 3 4 5 6 7 8 9
7. How much do I have to pay? 2 3 4 5 6 7 8 9

SITUATION 2

You have to appear for a job interview in Wilmington at 9:30 A.M. tomorrow. You want to take a bus.

The decision aid system will provide you with the answers to the questions below. Grade the importance of having the answers to these questions when you are in the situation described above.

Grade 2 is least important

Grade 9 is most important

1. When does the bus leave?	2 3 4 5 6 7 8 9
2. When does the bus reach my destination?	2 3 4 5 6 7 8 9
3. Is the bus stop far from the office?	2 3 4 5 6 7 8 9
4. Is there a bus back to Newark?	2 3 4 5 6 7 8 9
5. Do I have to transfer?	2 3 4 5 6 7 8 9
6. If so, how long do I have to wait to take the connecting bus?	2 3 4 5 6 7 8 9
7. How much do I have to pay?	2 3 4 5 6 7 8 9

Have you ever been in situations similar to this?

Yes, often ----- Yes, 2 or 3 times ----- Yes, once ----- Never -----

SITUATION 3

Every once in a while you take the DART bus from near your house to go to Christiana Mall. You know Rt. 5 goes there.

The decision aid system will provide you with the answers to the questions below. Grade the importance of having the answers to these questions when you are in the situation described above.

Grade 2 is least important

Grade 9 is most important

1. When does the bus leave?	2 3 4 5 6 7 8 9
2. When does the bus reach the Mall?	2 3 4 5 6 7 8 9
3. Is the bus stop far from the Mall?	2 3 4 5 6 7 8 9

4. Is there a return bus home? 2 3 4 5 6 7 8 9

5. Do I have to transfer? 2 3 4 5 6 7 8 9

6. If so, how long do I have to wait? 2 3 4 5 6 7 8 9

7. How much do I have to pay? 2 3 4 5 6 7 8 9

8. If I miss my return bus, how long do I have to wait for the next bus home? 2 3 4 5 6 7 8 9

Have you ever been in situations similar to this?

Yes, often ----- Yes, 2 or 3 times ----- Yes,once----- Never-----

SITUATION 4

You travel to school everyday by bus. Generally, you go back by 7 P.M. However, you just found out that today you have to attend a study group meeting at night in the Library. You are at school and after the meeting you would like to take a bus to go back home.

The decision aid system will provide you with the answers to the questions below. Grade the importance of having the answers to these questions when you are in the situation described above.

<u>Grade 2 is least important</u>

<u>Grade 9 is most important</u>

1. When does the bus leave? 2 3 4 5 6 7 8 9

2. When does the bus reach my home/dorm? 2 3 4 5 6 7 8 9

3. Is the bus stop far from my home/dorm? 2 3 4 5 6 7 8 9

4. Is there a bus home? 2 3 4 5 6 7 8 9

5. Do I have to transfer? 2 3 4 5 6 7 8 9

6. If so, how long do I have to wait to take the connecting bus? 2 3 4 5 6 7 8 9

7. If I miss my bus, how long do I have to wait for the next bus? 2 3 4 5 6 7 8 9

Have you ever been in situations similar to this?

Yes, often ----- Yes, 2 or 3 times ----- Yes, once ----- Never -----

SITUATION 5

You and your friends are planning to go to South Street in Philadelphia on Saturday evening. You do not want to drive back, so you are looking at the possibility of taking a train from Newark to Philadelphia and back.

The decision aid system will provide you with the answers to the questions below. Grade the importance of having the answers to these questions when you are in the situation described above.

<u>Grade 2 is least important</u>

<u>Grade 9 is most important</u>

1. When does the train leave? 2 3 4 5 6 7 8 9
2. When does the train reach South Street? 2 3 4 5 6 7 8 9
3. Is the train station far from where I want to go? 2 3 4 5 6 7 8 9
4. Is there a return train to Newark? 2 3 4 5 6 7 8 9
5. Do I have to transfer? 2 3 4 5 6 7 8 9
6. If so, how long do I have to wait to take the connecting train? 2 3 4 5 6 7 8 9
7. How much do I have to pay? 2 3 4 5 6 7 8 9
8. If I miss my return train, how long do I have to wait for the next train? 2 3 4 5 6 7 8 9
9. Do trains run on weekends? 2 3 4 5 6 7 8 9
10. How late can I take the train from Philadelphia? 2 3 4 5 6 7 8 9

Have you ever been in situations similar to this?

Yes, often ----- Yes, 2 or 3 times ----- Yes, once ----- Never -----

SITUATION 6

You are on a bus in Philadelphia and you are on your way to an important business appointment. The bus, however, is not running on time and you feel you might be late for the appointment. Therefore, you want to explore the possibility of taking the subway to reach your destination.

The decision aid system will provide you with the answers to the questions below. Grade the importance of having the answers to these questions when you are in the situation described above.

<u>Grade 2 is least important</u>

<u>Grade 9 is most important</u>

1. How late is it running?	2 3 4 5 6 7 8 9
2. Is it going to be delayed further?	2 3 4 5 6 7 8 9
3. What is causing the delay?	2 3 4 5 6 7 8 9
4. Can I take a subway to reach my destination?	2 3 4 5 6 7 8 9
5. How far is the nearest subway station?	2 3 4 5 6 7 8 9
6. When does the next subway train leave?	2 3 4 5 6 7 8 9
7. How soon can I reach my destination if I switch to the subway now?	2 3 4 5 6 7 8 9
8. What is the cost of taking the subway?	2 3 4 5 6 7 8 9
9. How far is my destination from here?	2 3 4 5 6 7 8 9

Have you ever been in situations similar to this?

Yes, often ----- Yes, 2 or 3 times ----- Yes, once ----- Never -----

How would you rate this survey?

Very easy ---- Reasonably easy ----- Somewhat difficult ----

Very difficult -----

Which, of the above situations do you find most difficult to imagine?

SITUATION 1 -----

SITUATION 2 -----

SITUATION 3 -----

SITUATION 4 -----

SITUATION 5 -----

SITUATION 6 -----

None -----

Do you have a car? Yes ----- No -----

THANK YOU

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Part II
DEVELOPMENT OF ITMS PROTOTYPES

Part II of this report develops and tests prototypes of ITMS, and also examines the possibility of integrating GIS as one of the features of ITMS. Two prototypes are presented here. One is a transit information delivery to a university community using the university computer system, which corresponds to a scenario under Phase 1 of the implementation stage (Section 8.3 of Part I). The other is a transit information delivery scheme using a hand-held computer as the user interface, which corresponds to a scenario under Phase 4 of the implementation stage.

Chapter 1
PROTOTYPE MODEL OF ITMS - PC/OFFICE COMPUTER BASED INTERFACE

A prototype system which delivers transit information to a large population using an existing computer network is presented here. It is designed to provide the students and the staff of the University of Delaware with the information of the University Bus service. The basic (static) information of the bus service is stored in the mainframe computer and individuals retrieve it at their workstation via computer network access in an interactive manner. The purpose of this prototype development is to show how transit information can be delivered in an office or home computer environment.

Consider the following scenario. A student is studying in the library at night and wants to find out the next available bus to his dormitory. He/she turns on a nearby PC in the library and obtains the departure time of the bus and any current information about the bus service (such as detouring or schedule change).

Like many universities, the University of Delaware operates a bus service for students, staff, and the faculty throughout the day in order to provide general convenience, security, and also to reduce the parking space requirements within the campus. Every student, staff and faculty is assigned an e-mail address and nearly all of them have ready access to desk-top computers which can be used as terminals to the mainframe computer. In this environment, information on the bus service can be stored in the main frame computer and anyone can retrieve it. (A similar service is available for checking the availability of library books at the University of Delaware).

The following is a summary of the features of this transit information access system. The system is created in the UNIX operating environment using the C language. It can be accessed from any computer linked to the university mainframe system. The command used for initiating the system is "UDBUS". By typing this command the user is presented with a screen shown in Figure 1.1.

To proceed further, the user must follow the instructions as they appear on the screen. Four categories of information are available as shown in Figure 1.2:

General Information

Bus Stop Location Information

Current Route Schedule

Bus Trip Planning

The General Information menu is used for news items, events, announcements on route or bus schedule changes, and any changes in bus operations. This menu is also used for introducing the system to the users. Figure 1.3 displays the screen as it appears while using the General Information menu.

Information on bus stop location is obtained by pressing the key "L". A list of all the bus stops in the bus service will appear and specific descriptions of the locations will also appear. Users may further select a bus stop location and view the map showing the vicinity of the bus stop. Figure 1.4 presents the Bus Stop Location Information menu, and Figure 1.5 presents the map for Smith Overpass, a popular bus stop.

The current schedule of any route can be obtained by entering the key "S". This menu lists all the bus routes operated by the University as shown in Figure 1.6. The user can select any of the bus routes and a complete schedule of the selected route can be obtained, as shown in Figure 1.7.

The user can also plan his/her trip by pressing "P" in the initial menu. The computer asks the day of travel first. This is necessary as the bus schedule for weekdays

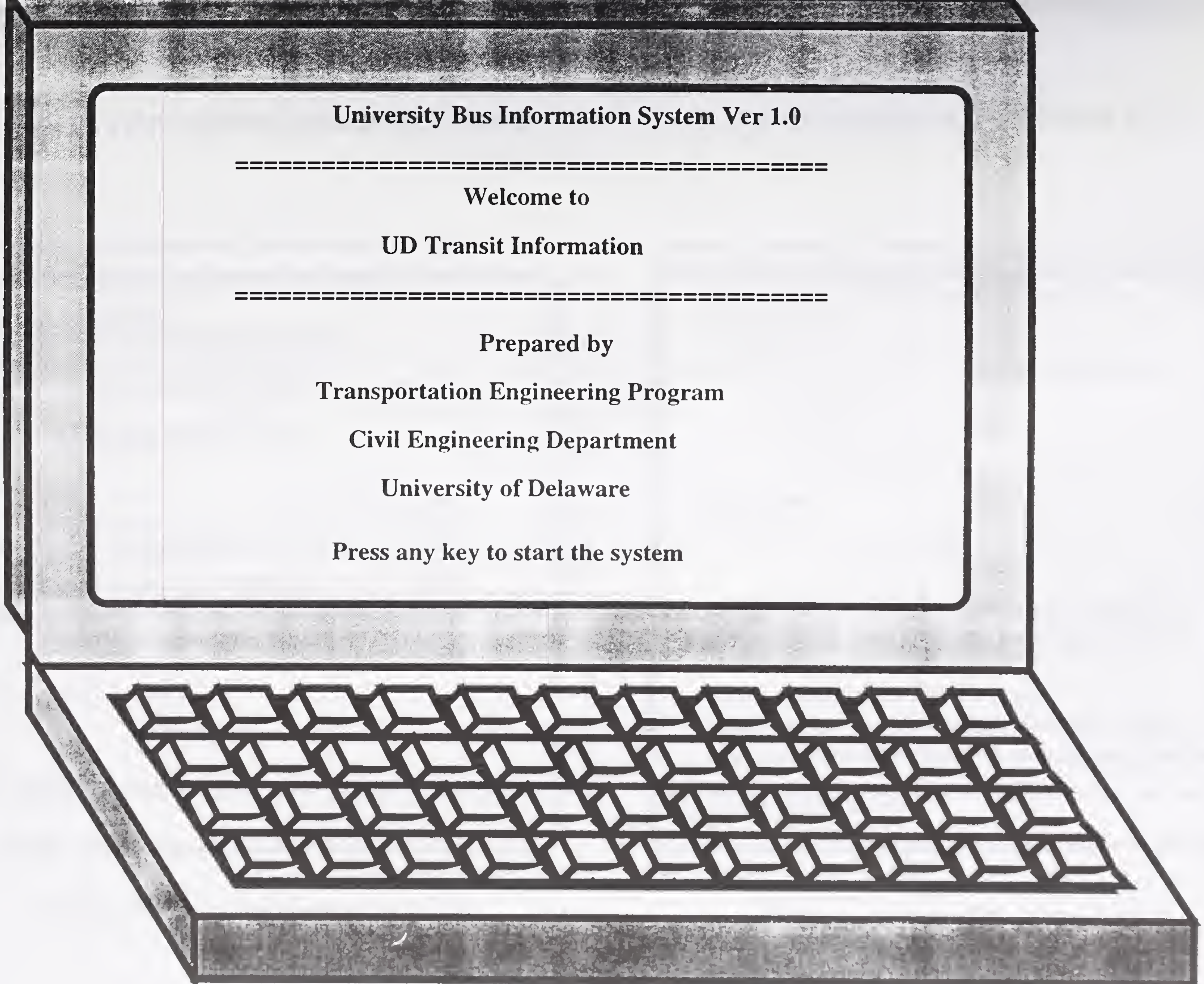


Figure 1.1 First Screen of the University Bus Information System Version 1.0

University Bus Information System Ver 1.0

Main Menu

General Information ....[I]
Bus Stop Location Information ....[L]
Current Route Schedule ....[S]
Bus Trip Planning ....[P]
Exit System ....[E]

Press key for function

[Main Menu]

Figure 1.2 Main Menu of Information System

General Information

* This area is used for placing general information such as news, events, announcements on route changes, time-table changes, etc.

* It can also be used for introducing this system and for instructing the users on how to use it.

[Main Menu]

Figure 1.3 General Information Menu

University Bus Information System Ver 1.0

Guide to Bus Stops and their Locations
Choose a bus stop and press [Enter].
It will give you a map of the selected bus stop location.

Bus Stop Location

Bus Stop	Full Name	Location Information
St Cen	Student Center	On Academy St., in front of Book-Store.
Commons	Christiana Com.	Off 896 North, in front of Towers
Smt Pass	Smith Overpass	On South College Ave, near Smith Hall
~	~	~

[N]ext [P]rev. [Enter]

Figure 1.4 Bus Stop Location Menu

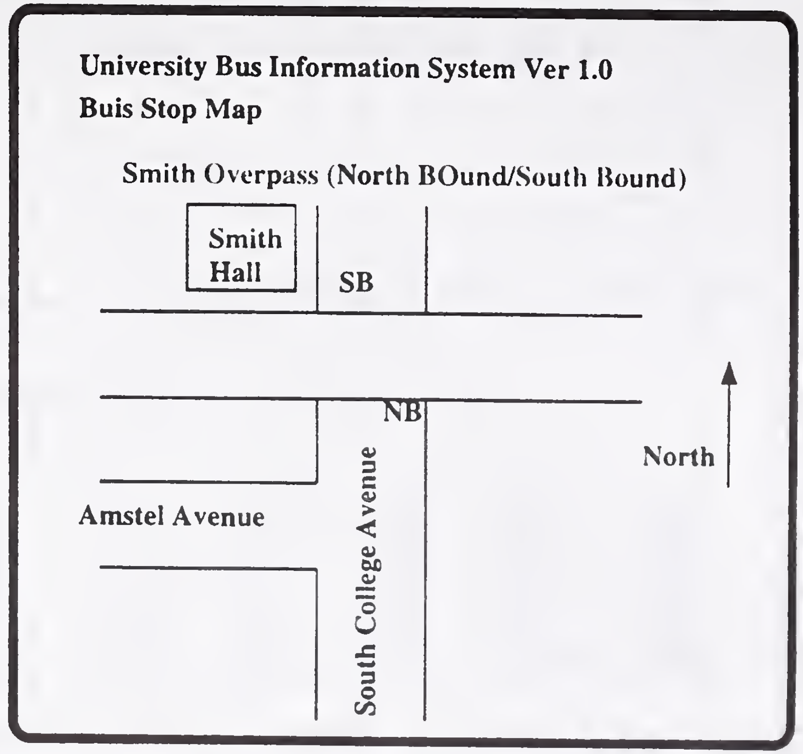


Figure 1.5 Bus Stop Map Display

University Bus Information System Ver 1.0

Guide to Bus Routes and their Schedules

Choose a Bus Name and Press [Enter].
It will give you a schedule of the selected bus route.

Bus Routes

Bus Name	Days	Operation Hours	Major Bus Stops
Bus A	Mon-Fri	7:36am- 2:21pm	Smith-Towne-Commons
Bus B	Mon-Fri	7:35am- 6:59pm	Smith-Field-Commons
Loop 1	Mon-Fri	7:32am- 6:54pm	Smith-Towne-Paper-Field-Commons
Loop 2	Mon-Fri	7:30am- 6:45pm	Smith-St.Cen.-Field-Commons
Loop 3	Mon-Fri	7:30am- 6:45pm	Smith-Towne-Field-Ray-Paper
Loop 4	Mon-Fri	7:40am- 2:26pm	Smith-Commons-Field-Ray

[N]ext [P]rev [Enter]

Figure 1.6 Bus Route Information Menu

University Bus Information System Ver 1.0

Guide to Bus Routes and their Schedules

Route : Bus A Days : Mon-Fri Hours : 7:36 am - 2:21 pm

Schedule

St. Center	C. Commons	Smith OP	Towne Ct.	Park Place	Smith OP
------------	07:36	07:42	07:48	07:50	07:56
)9:02	09:08	09:14	09:20	09:25	09:34
10:02	10:08	10:14	10:20	10:25	10:34
11:02	11:08	11:14	11:20	10:25	10:34
12:02	12:08	12:14	12:48	12:50	12:56
13:27	13:36	13:42	13:48	13:50	13:56

[N]ext [P]rev [Enter]

Figure 1.7 Schedule for "Bus A"

is different from the schedule for weekends. The trip planning screens are presented in Figures 1.8 and 1.9. After the user selects the desired day of travel, he is asked to select the approximate time of the day for which he wants to plan the trip. Here, he can either enter "All Day" to view the schedule for the entire day, or he can enter a specific time during the day in the format "hh:mm" (hours:min) to view the schedule around that time of the day. Next, the user is presented with a list of all the bus stops and asked to select the origin and destination of travel. Once the user has selected the destination of travel, he is presented with a schedule of buses at the two stops. The information presented here is for the buses that run between the two stops around the time indicated by the user. This is illustrated in Figure 1.10. In this figure, the information presented is for the entire day as the user had asked for bus schedule information for "All Day".

After going through these four stages, the user can exit from the system by pressing "E" and will see a screen shown in Figure 1.11. The user can exit from the system at anytime by pressing the letter "E" in the Main Menu.

Presented above is a prototype of an information system which can be introduced in most work or school environments. Today computer communications allows for a transit agency to send information to the mainframe computer of an organization and the employees view it via personal terminals. This scheme will allow the most updated information to be sent to the potential users; for example at the time of snow storms. The transit agency can reduce the manpower needed for telephone inquiries and the user will have less waiting time for the inquiry to be answered. By allowing the user to print out the screen display, the transit agency can reduce the burden of mailing schedules.

University Bus Information System Ver 1.0

This Module helps you in planning your trip.
Enter your request by selecting from the following menu.

Which Day of the Week?

Monday-Friday (weekday)
Saturday-Sunday (weekend)

[N]ext [P]rev [Enter]

Figure 1.8 Trip Planning Menu (Selection of Day)

University Bus Information System Ver 1.0

This Module helps you in planning your trip.
Enter your request by selecting from the following menu.

What day : Monday - Friday
What time : All Day
Origin : Smith Overpass
Destination:

Feasible Schedule

Smith OP	Ray St.
8:23 am	8:52 am
9:21 am	9:49 am
2:53 pm	3:24 pm
4:49 pm	5:18 pm
5:45 pm	6:13 pm

[N]ext [P]rev [Enter]

Figure 1.9 Trip Planning (Selection of Origin)

University Bus Information System Ver 1.0

This Module helps you in planning your trip.
Enter your request by selecting from the following menu.

What day : Monday - Friday
What time : All Day
Origin : Smith Overpass
Destination : Ray Street

Feasible Schedule

Smt OP	Ray
8:23am	8:52am
9:21am	9:49am
2:53pm	3:24pm
4:49pm	5:18pm
5:45pm	6:13pm

[N]ext [P]rev [Enter]

Figure 1.10 Feasible Schedule Display

University Bus Information System Ver 1.0

Have a Good Day

Quit System [y/n] ? y

Figure 1.11 Exit Menu Screen

Chapter 2

PROTOTYPE MODEL OF ITMS HAND-HELD COMPUTER BASED INTERFACE (TRANSPAL)

The prototype ITMS presented here is called TRANSPAL. It is a user interface device consisting of a "palm-top" computer which contains decision aid algorithms. The purpose of developing this prototype is to demonstrate a scenario in which a user communicates with the central information processor to obtain transit information via a portable device. TRANSPAL easily fits a person's palm and its photograph is shown in Figure 2.1.

2.1 Scope of Operation of TRANSPAL

TRANSPAL contains transit information for the northern New Castle County, Delaware, and it demonstrates an ITMS environment when a user needs to make a decision about travel using DART (Delaware Administration for Regional Transit). Because of the lack of the central information processing facility, this TRANSPAL can only present the static information; however, under Phase 4 of ITMS implementation discussed in Part 1, TRANSPAL could be plugged into a public telephone and the user inquiries would be answered in real time. The scope of TRANSPAL is illustrated in Figure 2.2. TRANSPAL performs the following functions:

- Stores schedule information - this function can be performed by the central information processor under the full-scale ITMS,
- Retrieves the information and executes the algorithm which determines the most suitable routes and schedules for a given travel situation, and
- Presents the information to the user.

The user input to TRANSPAL is the following:

- origin and destination of travel,
- desired departure time at the origin, and
- desired arrival time at the destination.

Figure 2.1 TRANSPAL - Your Portable Transit Pal

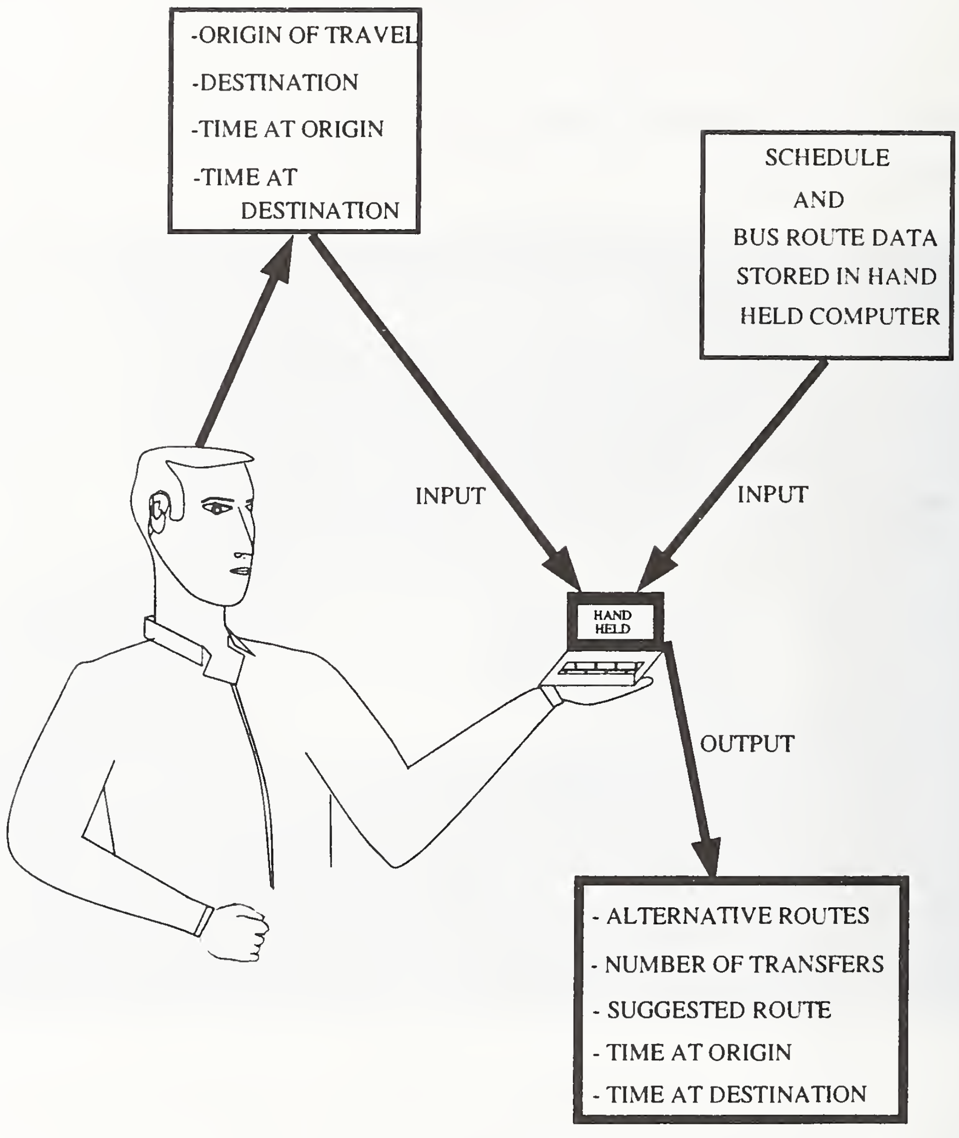


Figure 2.2 Scope of Operation of TRANSPAL

Based on this input, TRANSPAL searches and develops an itinerary that best meets the user's desire. The itinerary prepared by TRANSPAL includes:

- suggested route,
- suggested departure time at origin and the expected arrival time at destination,
- the number of transfers involved,
- arrival and departure times at each transfer point,
- alternative routes with information on departure and arrival times and transfers (if any), and
- schematic map of the suggested bus route.

TRANSPAL has two major elements: the user interface and the decision-aid algorithms. The features by which information is displayed on the screen in response to the use of function keys constitute the user interface. They are explained in section 2.2. The decision aid algorithms are a path search algorithm and the itinerary evaluation and they will be explained in section 2.3.

2.2 How to Interface with TRANSPAL

The user interfaces with TRANSPAL through five function keys on the "palm-top" computer. Each of the keys (from F1 through F5) is assigned one activity. Assignment of function to each key follows a certain logical sequence. The user must follow this sequence in order to get a complete and meaningful trip plan.

A flow chart of TRANSPAL operation in Figure 2.3 presents the order in which the function keys are to be operated. Table 2.1 explains the sequence of operation of the function keys and shows the contents of the screen display for each function key. Figure 2.4 displays the screen when TRANSPAL is in operation. It also presents the hierarchical linkage of the various functions.

The user can break the sequence of operations and exit from the system by pressing the F5 key at any time. The next section discusses the functioning of each of the keys in some detail.

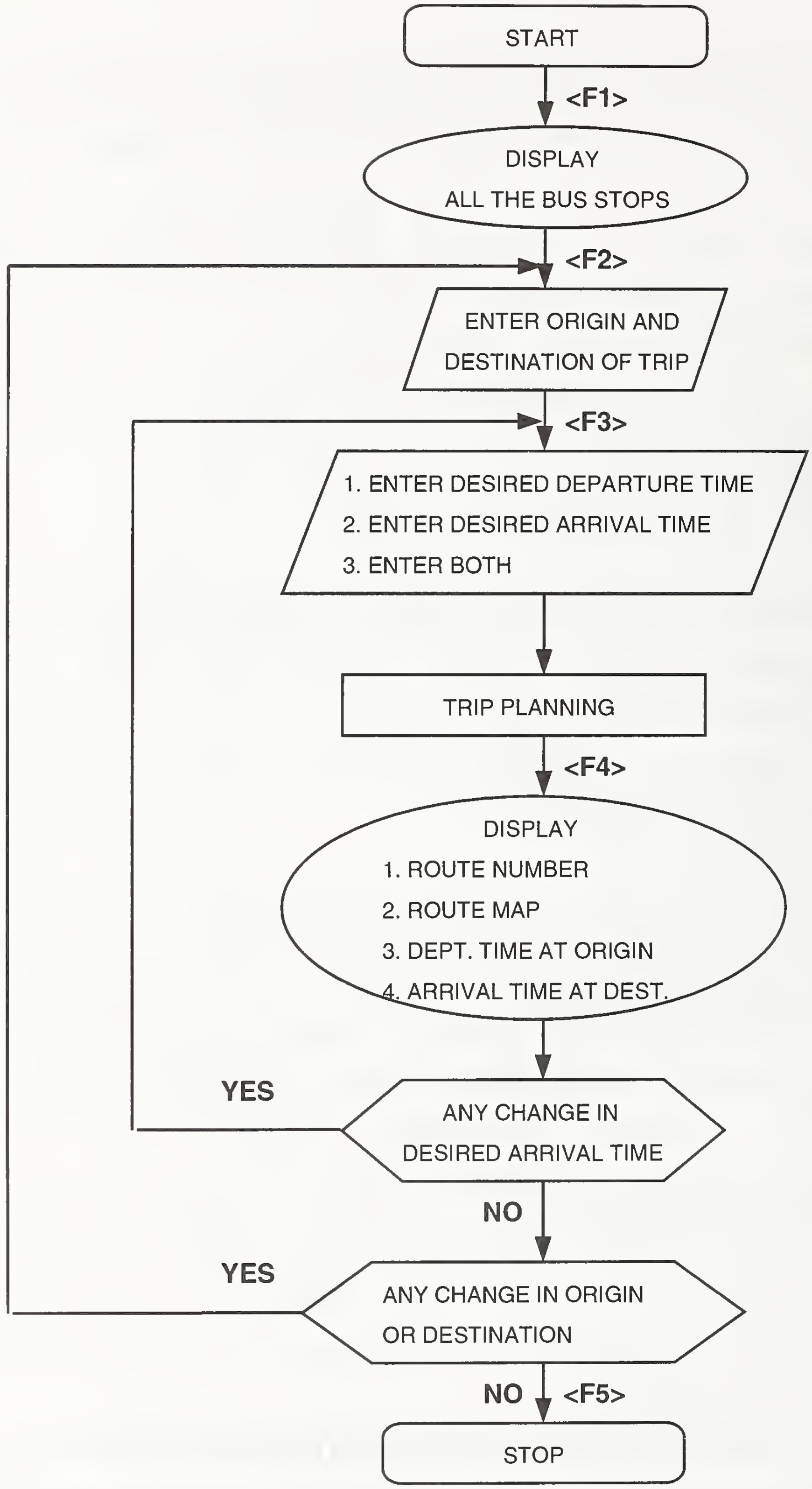


Figure 2.3 Flowchart of Prototype Operation

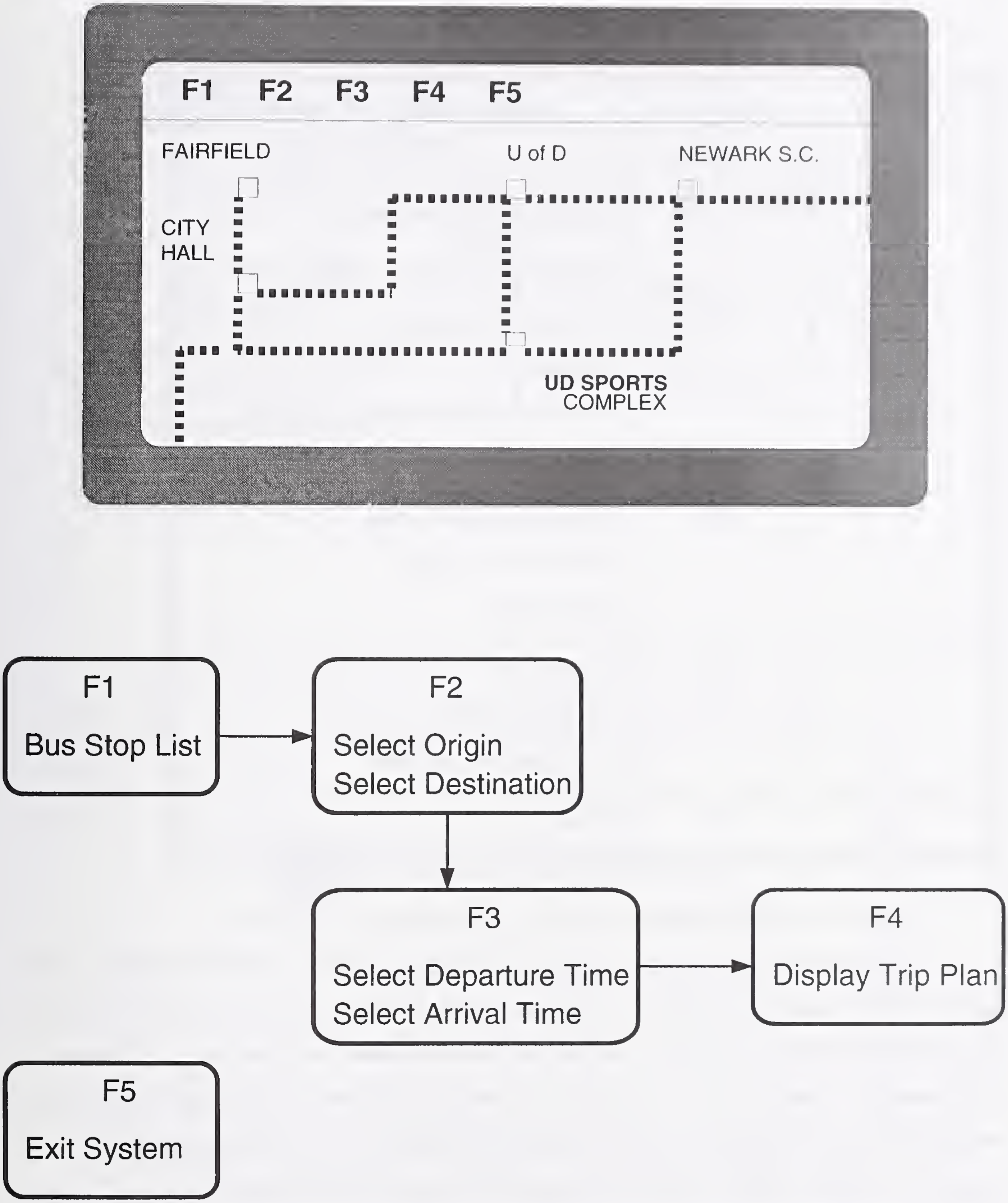


Figure 2.4 Original TRANSPAL Display and Hierarchy of Functions

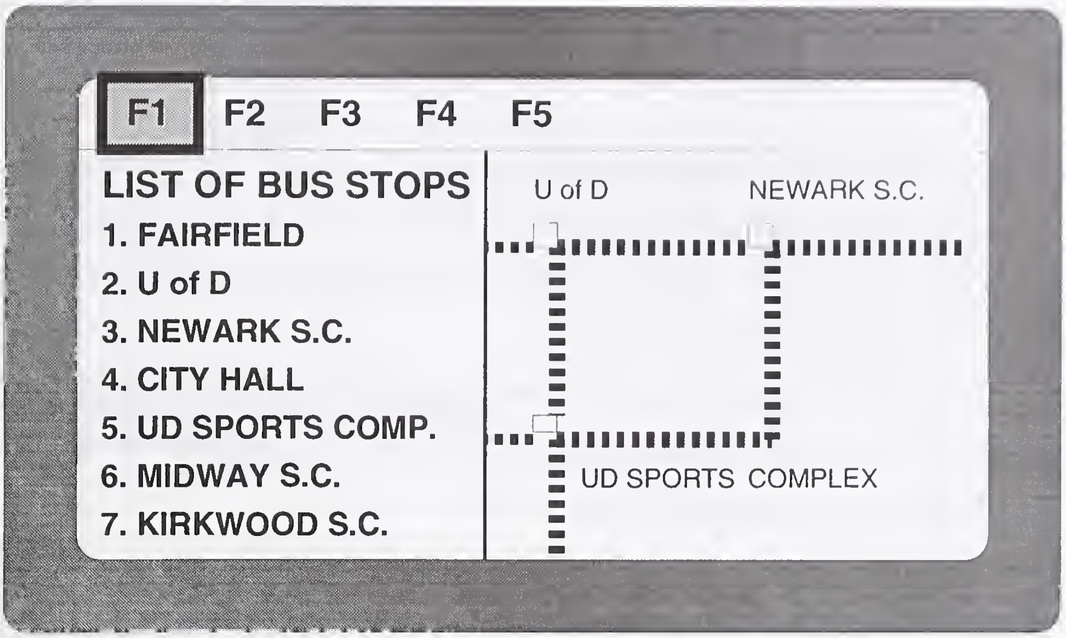
TABLE 2.1 Function key operation

Operation Number	Function Key	Screen Display and options
1	F1	1.List of all the bus-stops 2.Bus-stop location on map
2	F2	1.Enter origin and destination 2.Display of origin and dest. locations on map
4	F3	1.Enter departure time 2.Enter arrival time 3.Enter both
4	F4	1.Route No. 2.Departure time at origin 3.Arrival time at dest.
5	F5	Exit

In the following, functions of each key operation are explained.

Function <F1>:Bus stop location. On pressing <F1>,a list of bus stops in the transit service areas is displayed. If the user wants to see the location of a bus stop on a map, then he should move the cursor to the bus stop name and then press <Return>. On pressing <Return>, the location of the bus stop is shown on the map. This function will help the user visualize the stop location with respect to the other stops in the network. Refer to Figure 2.5 for a display of the screen after operating the <F1>key.

Function <F2>:Trip end locations. On pressing the <F2>key, the computer prompts the user to enter the origin and the destination of the trip. To enter the origin, the user moves the cursor to any name on the list of bus stops and presses <Return>.



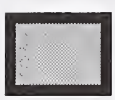
 - Function in Operation

Figure 2.5 Functions of the <F1> key

This will generate a map of the area; the bus stop location will appear highlighted on the map.

At this point, the user enters the origin by either selecting the highlighted bus stop, or by selecting any of the adjacent stops which the user feels more appropriate as the origin. In other words, the user has the option of changing the selection of the origin of travel after viewing the map of the area.

Similarly, the user can select the destination of travel by first viewing the map, and then selecting the desired destination stop on the map. Figure 2.6 shows the process of selection of origin and destination of the travel.

Function <F3>:Desired times at origin and destination. On pressing the <F3> key, the user is asked to enter either the desired departure time at the origin, or the desired arrival time at the destination, or both. The user must enter the time in the 24 hour clock format. For example, 11 am should be entered as 11:00, and 10 pm as 22:00. Figure 2.7 shows the process of selecting the desired departure and arrival times.

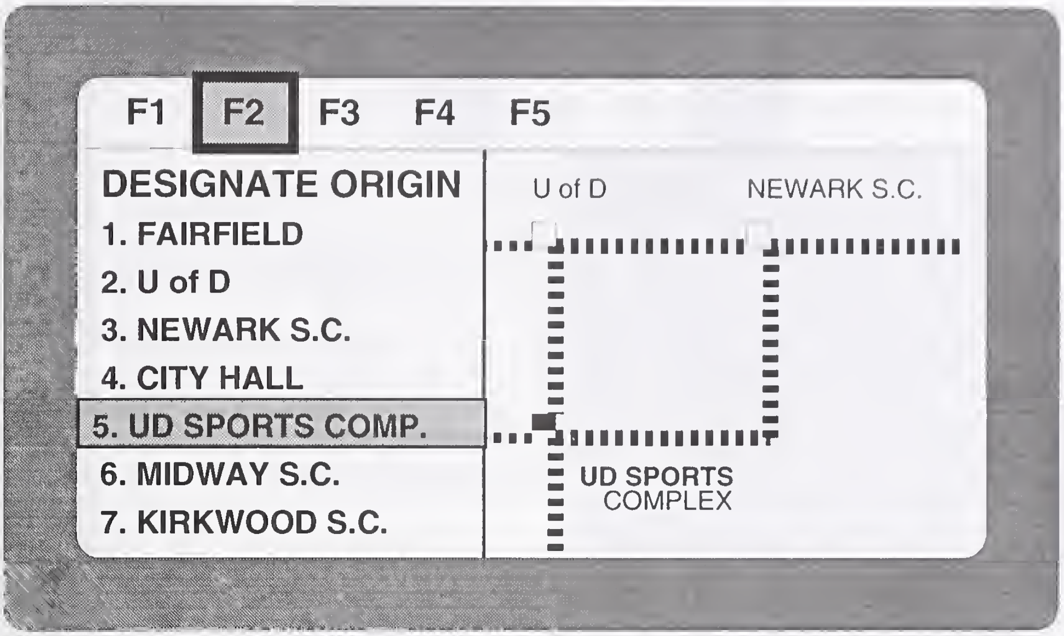
Function <F4>:Trip plan display. On pressing the <F4>key, the screen displays the bus route numbers which accommodate the origin-destination trip of the user and its map. The departure time at the origin and the expected arrival time at the destination are also shown. Figure 2.8 shows the trip plan as it appears on operating the <f4>key.

Function <F5>:Exit. On pressing the <F5>key, the user exits from the information system at anytime.

2.3 Decision-Aid Algorithms

TRANSPAL matches the traveler's desire with the available transit service and prepares a travel itinerary for the desired travel. Two algorithms which support TRANSPAL are path search and schedule evaluation.

The travel itinerary is computed by first performing a path search to determine alternative routes connecting the origin and destination pair. The second step is to determine the most suitable schedule from the alternative routes depending on the travel requirements of the traveler. These algorithms are explained in the following.



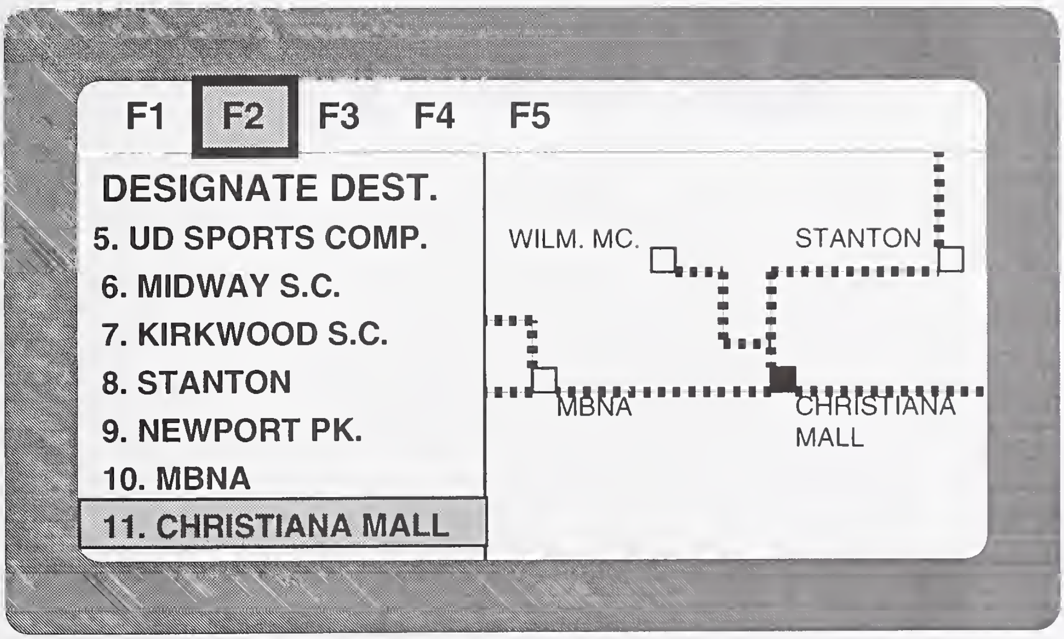


Figure 2.6 Functioning of F2 Key

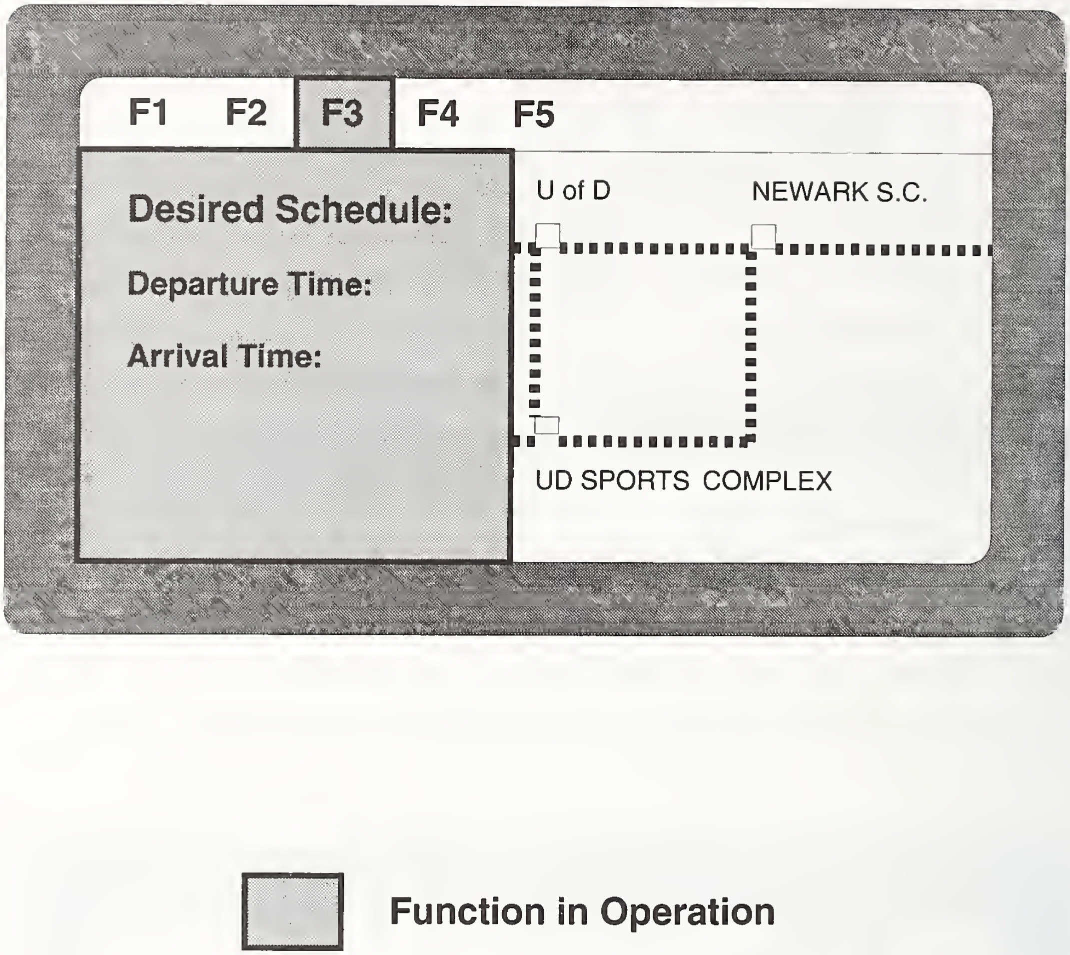


Figure 2.7 Functioning of <F3> Key

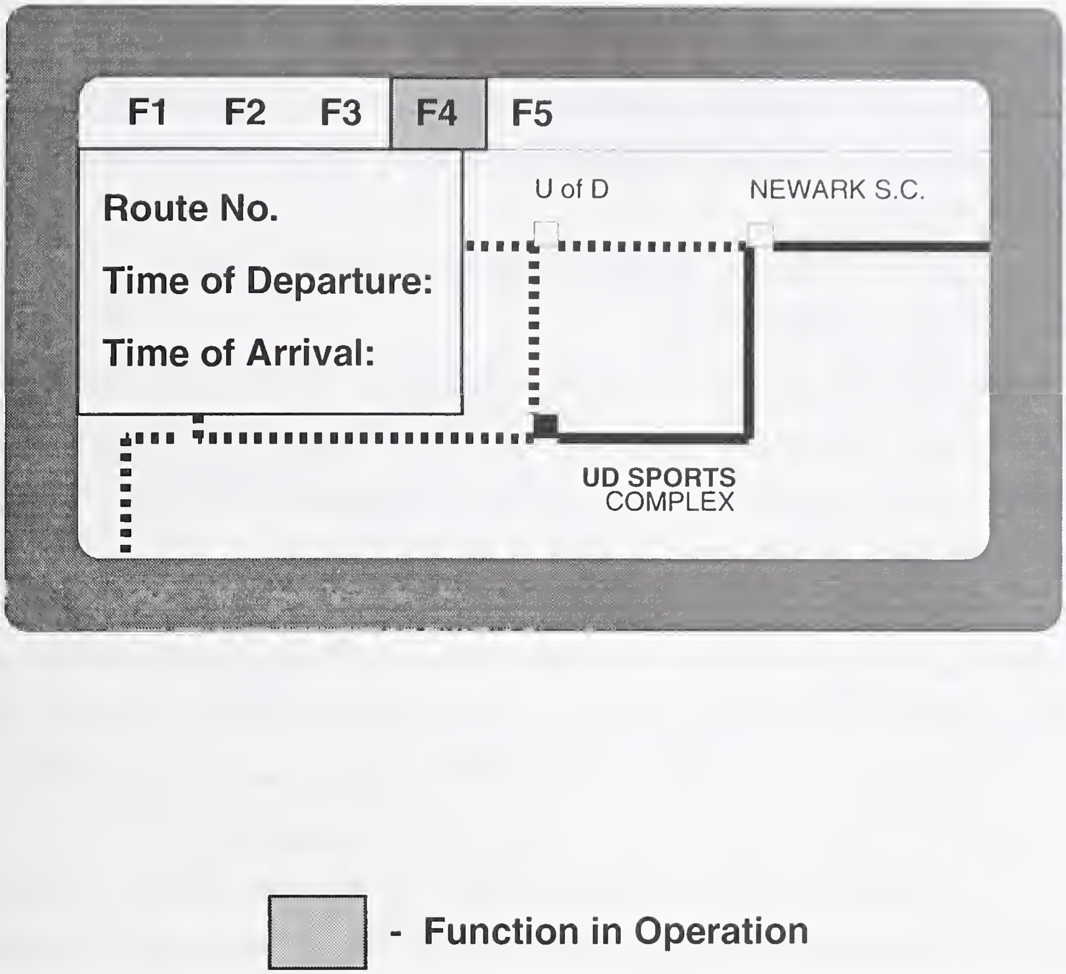


Figure 2.8 Final Trip Plan Display

2.3.1 Path Search Algorithm

The path search algorithm calculates the shortest route between the origin and destination selected by the user. Definition of the term "shortest" may be based on either of the following criteria:

- minimum number of transfers associated with the route, or
- minimum travel time for the route.

While the minimum total travel time is usually the most logical criterion, a path with a short travel time may involve several transfers between the origin and the destination. Generally speaking, a route with the least number of transfers or the most direct possible route is considered the most "convenient" route.
Thus, the shortest path algorithm developed for, and employed by TRANSPAL yields the route which has the least number of transfers between the origin and destination pair.

The algorithm sets a maximum limit on the number of transfers allowed. For the purpose of TRANSPAL, one transfer was considered to be a satisfactory upper limit, considering the size of the bus network in New Castle County (Delaware).

A few preliminary steps are executed before the algorithm proceeds. First, the user enters the origin and destination of travel on the bus network map. The origin and destination are then located on the previously stored bus network and all possible connecting routes are drawn. TRANSPAL stores the network and refers to it whenever a calculation is made.

Each bus stop is labeled a number equal to the lesser of: the number of intermediate stops between that stop and the trip origin, and the number of intermediate stops between that stop and the destination. Stops which can be arrived at from either the origin or the destination by passing through "N" number of intermediate bus stops are said to lie on the Nth boundary. For example, all the bus stops which are adjacent to the origin and destination are said to lie on boundary number 1. Figure 2.9 illustrates all the bus stops in the vicinity of the origin and destination, and the boundaries on which they lie. After these preliminary steps, the route search algorithm proceeds.

The route search is exhaustive and considers all the possibilities for connecting the origin and destination through various bus routes. The algorithm proceeds in the

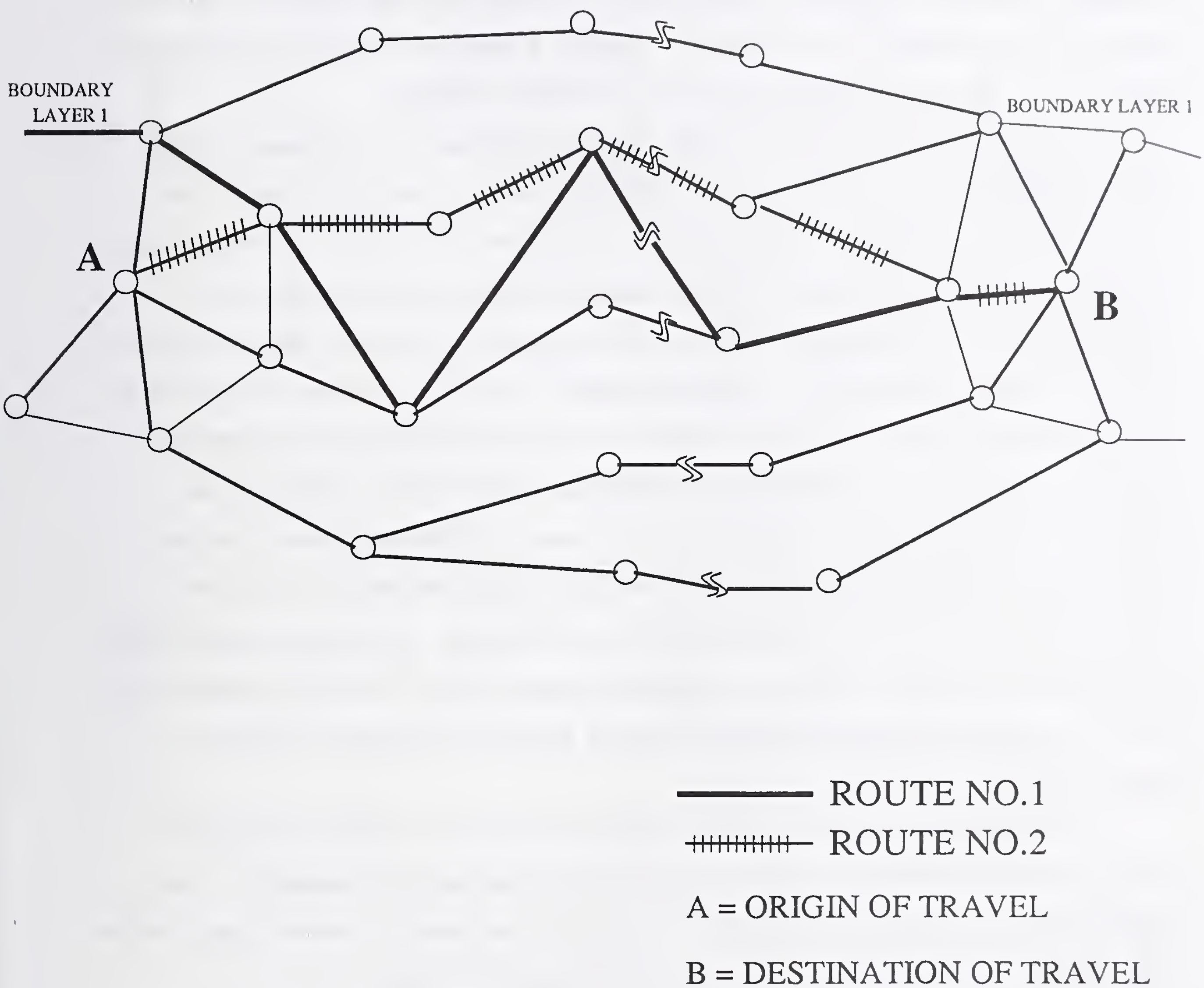


Figure 2.9 Illustration of Origin and Destination of Travel and Other Bus Stops in the Network

following steps:

STEP 1. From the origin of travel, expand the search to all the bus stops on boundary number 1. Assign a number to all the bus stops (referred to as nodes) equal to the number of transfers required to reach these bus stops from the origin. For all the bus stops on the first boundary, the number of transfers is equal to 0. Figure 2.10 illustrates these values at the first boundary level after one search iteration.

STEP 2. Expand the search around both the origin and the destination, to the second boundary. If any node (bus stop) can be approached from two or more routes, consider the route that requires the least number of transfers to get to that node. Label all the nodes based on the least number of transfers required to reach them. For example, in Figure 2.10 the node labeled "Q" can be reached from two different routes. If Route 1 is used, the number of transfers required is equal to 1. If Route 2 is used, no transfer is required. Thus, the node is labeled "0",representing the least number of transfers along any route required to get to the node from either the origin or the destination. This procedure continues until the boundary layers expanding from the origin and the destination meet. The node that falls on the intersection of the two boundary layers is part of the bus route with the least number of transfers. Based on the least number of transfers criterion, the algorithm selects Route 1. Refer to Figure 2.11 for the route selected after performing the search process at the second and third boundary levels.

One advantage of this algorithm is that it can find a near optimal solution for other criteria like the shortest distance between the origin and the destination. The algorithm, however, will need modifications if it is to deal with bus networks that involve "loops" in the routes. (This is currently not possible in TRANSPAL).

2.3.2 Schedule Evaluation with Human Criteria

A problem associated with trip planning by a computer based algorithm is that the meaning of human desire cannot be precisely translated in the algorithm. For example, if one enters 1400 hours when asked about the desired arrival time at the destination, in most situations the user would be referring to a time "around" 1400 hours. A computer cannot understand the uncertainty associated with most human decisions.

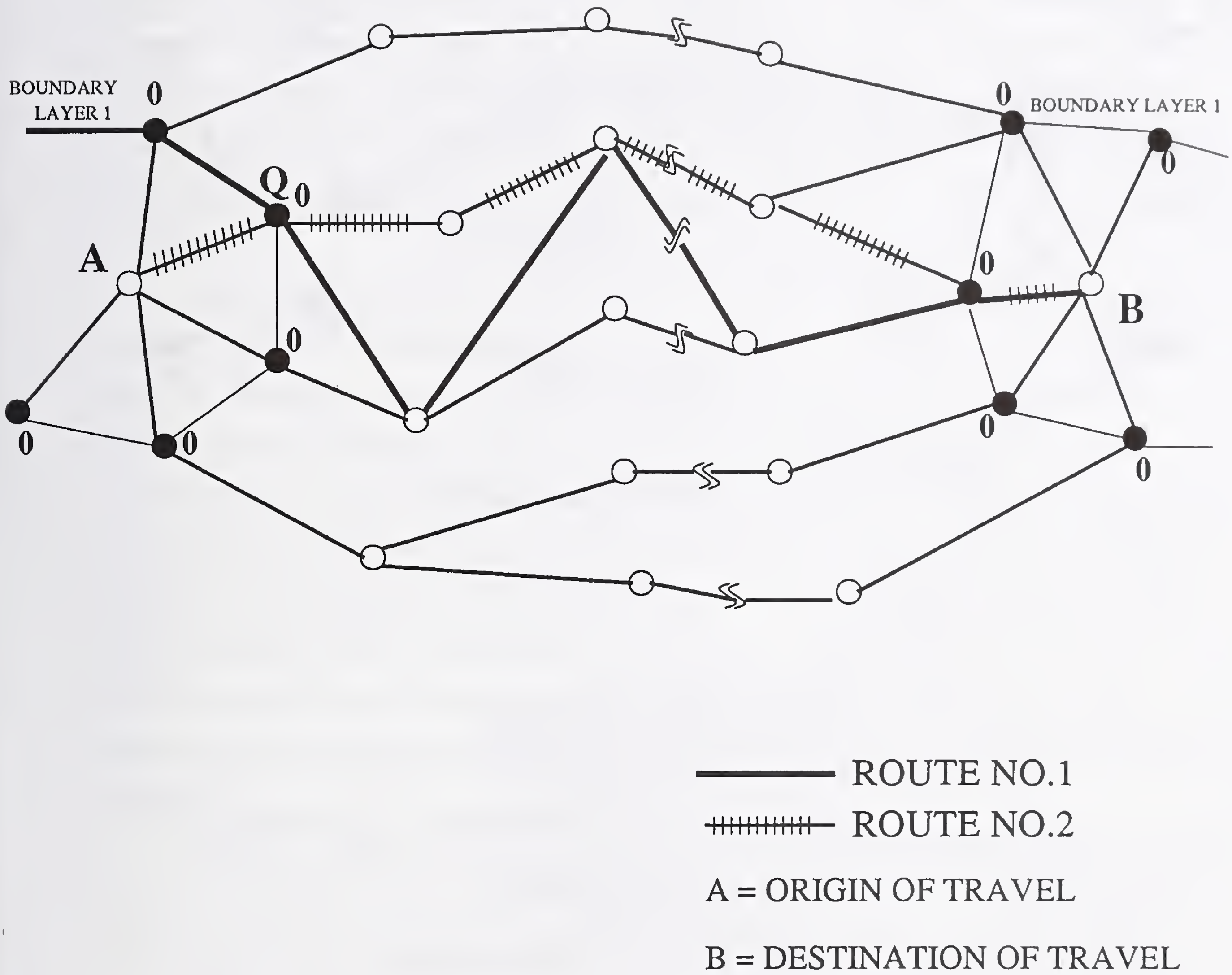


Figure 2.10 Search Process at First Boundary Layer

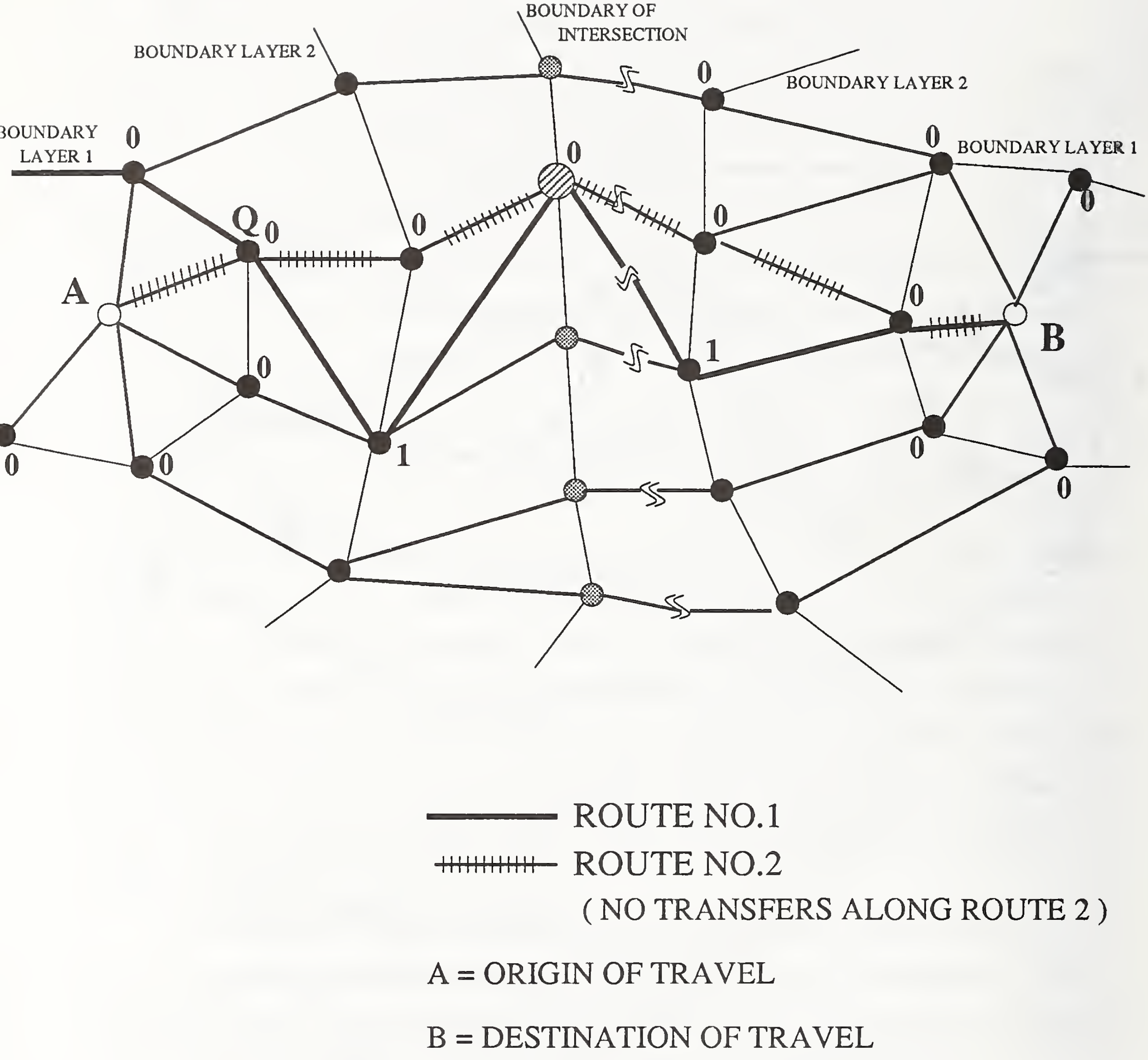
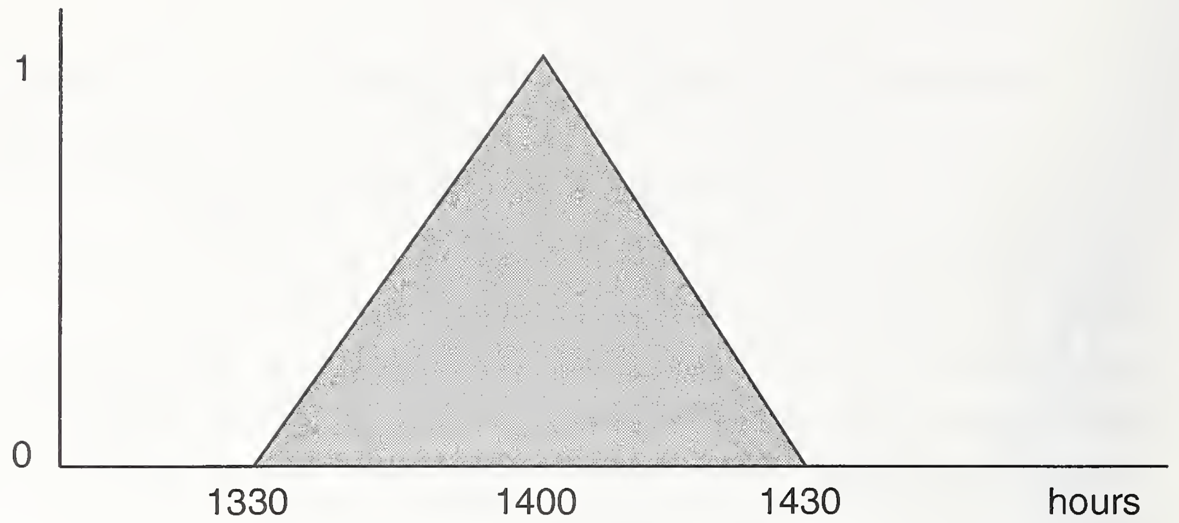


Figure 2.11 Search Process at Second and Third Boundary Layers: Illustration of Selected Route

This vagueness in the traveler's desire is accounted for by using the concept of fuzzy sets. Fuzzy sets are the sets whose boundaries are not clearly specified. It is defined by using a membership function which represents the degree that an element satisfies the notion of the set. Figure 2.12 (a), illustrates the shape of a membership function of a fuzzy set "around 1400". The height of the function indicates the membership degree of each element (time). Any individual can uniquely specify the shape of his fuzzy set to indicate his personal definition of the term "around 1400" hours. The same idea is applied to the definition of "short transfer time" as illustrated in Figure 2.12(b).

Suppose that there are two buses which take the traveler to his destination "around" 1400 hours. One of the buses reaches the destination at 1342 hours and the other at 1410 hours. The conventional mathematical solution to this problem would suggest a time of 1410 as it is closer to 1400 compared to 1342. Yet, in reality, the traveler may be a punctual person and thus prefer the 1342 bus. Figure 2.13 depicts that the satisfaction levels associated with arrival at 1410 hours and 1342 hours, respectively; the former being 0.3 and the latter 0.5. The shape of the membership function would differ depending on the circumstances of travel; for a shopping trip and for a job interview trip the concept of time would be quite different. The difference can be defined by the membership function and accordingly the recommended itinerary will be different.

Another example is illustrated by Figure 2.14 in which the traveler transfers from one bus to another. In such a situation, the criterion for the traveler's decision may be based on transfer time or the arrival time at the destination. This situation indicates a multi-criteria problem and fuzzy sets can handle such problems as shown in the figure. The transfer time at the transfer point is 28 minutes and the arrival time is 13 minutes before the desired arrival time. The satisfaction levels associated with the two criteria are equal to the associated membership values. In this case, the satisfaction level associated with the arrival time is more than that associated with the time spent at the transfer point. In some other situation, however, the satisfaction value associated with the transfer time may be higher.



a) Desired Arrival TIme (Around 1400 hours)

b) Short Transfer Time

Figure 2.12 Fuzzy Membership Functions for "Around 1400" and "Short Transfer Time"

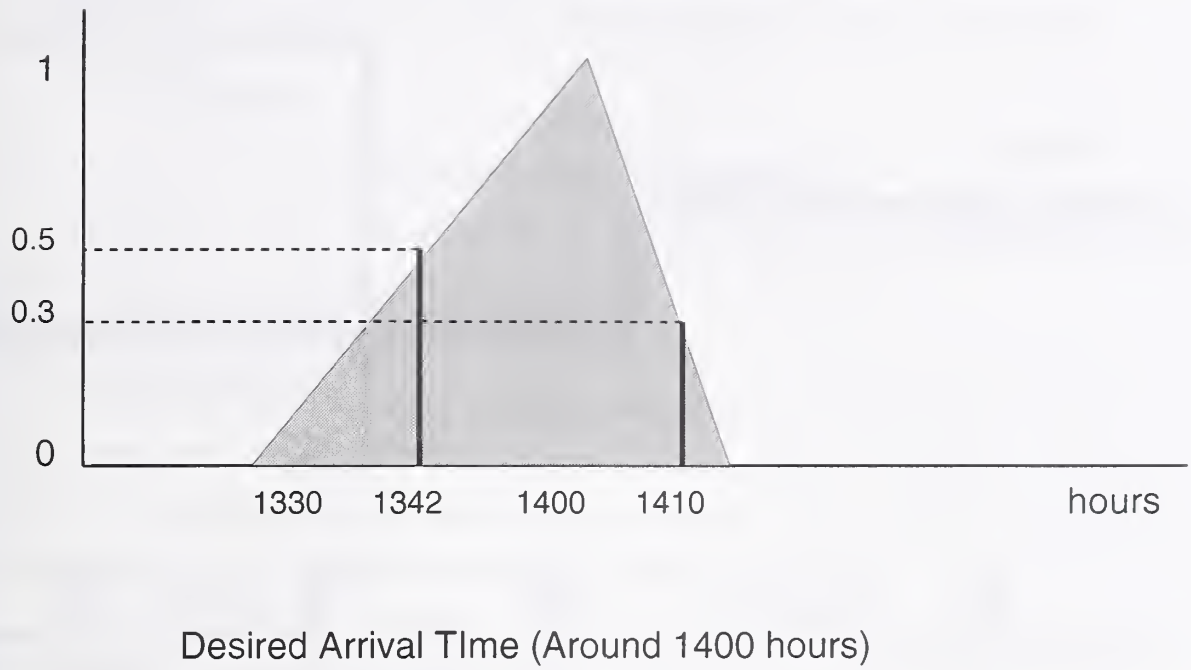


Figure 2.13 Membership Values for 1342 and 1410 hours in the Set "Around 1400 hours"

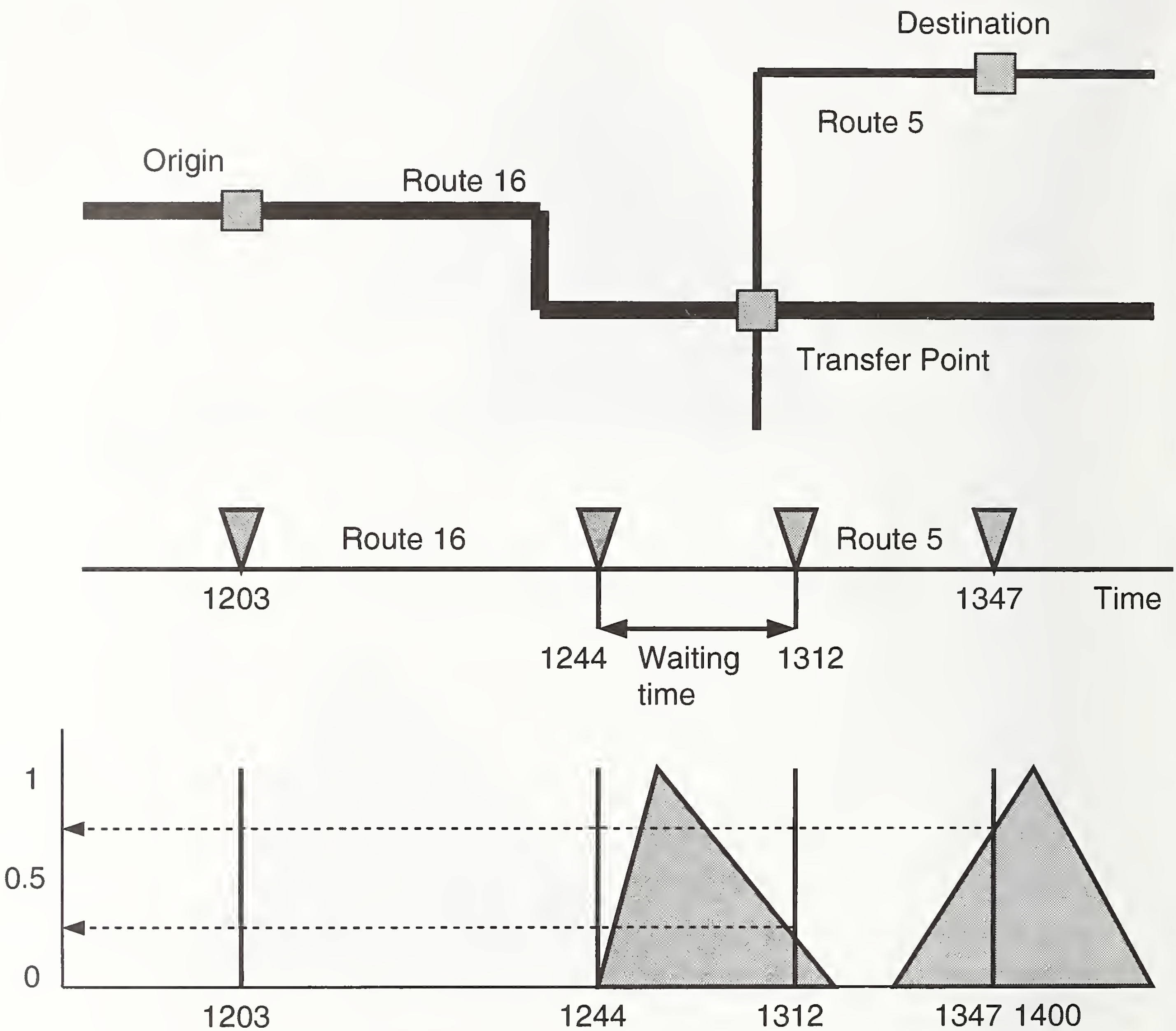


Figure 2.14 Decision Making During Trip Planning: Use of Fuzzy Logic

TRANSPAL utilizes fuzzy sets as the traveler's notion of desire and evaluates the recommended routes and itinerary. Further, it presents these routes in a descending order of preference.

2.4 Evaluation of TRANSPAL Capability

This section evaluates the limitations of using the current hand held computer for the user interface of ITMS through the experiment with TRANSPAL.

2.4.1 Limitations and Problems

Limited memory. TRANSPAL resides in a Hewlett Packard (95LX) hand held computer. The memory size is 1MB RAM and it cannot support all the functions that TRANSPAL should be capable of performing. For example, some of the bus routes had to be modified in order to meet the computer memory requirements.

Software limitations. At present, the only language that the hand-held computer supports is BASIC which allows a rudimentary graphic display of the transit network map. Another problem is the rather slow computation speed. With advances in technology, however, it may be possible to overcome these limitations.

Power limitation. As mentioned earlier, the computer requires two 1.5 volts dry cell batteries. While it can also function using an AC adapter and a regular power source, the portability of TRANSPAL will be limited by the number of hours the batteries can sustain the power.

Cost. The hand-held computer is priced around $500 at present. The price of the computer, however, may be reduced to a level which can be afforded by most transit users (particularly choice riders) in the near future, as has been seen in the past.

Standardization of information format. One of the important aspects which will probably hinder the feasibility of ITMS on the universal basis is the lack of a standardized format of transit information. At present there is no uniformity in the format that transit schedules, fares and networks are presented. Each city has adopted its own format for the system. Considering the uniqueness of the transit operations in each city, it may not be possible to universally standardize the presentation format; however, it would be much easier to prepare the software if the information format is standardized. Such standardization would allow the traveler to access ITMS in different cities and obtain transit information, which is one of the main objectives of ITMS.

2.4.2 Improvement Possibilities

Most of the limitations mentioned above may be overcome with the advances in computer technology which are inevitable with time. For example, the memory size will be increased and high quality color display will become possible. This improvement will enable the display of GIS maps of the transit network. With higher computation speed and more memory, large software can be stored and executed in a short time. With these improvements, the computer will be able to hold the schedules of larger and more complex transit networks than the present TRANSPAL and provide the itineraries in a very short time.

Chapter 3

APPLICATION OF GEOGRAPHIC INFORMATION SYSTEM (GIS)

Spatial data are critical elements of transit information. Tasks of route search, map displays, and storage of a large quantity of spatial data require computer software specially designed to handle spatial data, commonly refereed to as Geographic Information Systems (GIS). To demonstrate the applicability of GIS to ITMS, a prototype was implemented on an IBM 486 lap-top computer using an existing GIS software package called TransCAD. The scope of this demonstration is limited to visual presentation of the DART bus routes along with possible demand locations. This chapter presents the process of development of the prototype GIS for ITMS in three sections. The first section discusses the process of acquiring a suitable database. The second section delineates the process of development of the bus routes database. The third section studies the development of the databases for bus stops and other landmarks in New Castle County, Delaware.

3.1 Acquisition of an Initial Database

The first step in developing the prototype was to obtain a suitable database for the GIS. The TIGER files developed by the U.S. Census Bureau were chosen for this purpose. TIGER files make up an extensive database which include geographic features scanned from U.S. Geological Survey maps such as roads, railroads, and rivers; census geographic area codes; address ranges; and latitude/longitude coordinates for all points [16]. These files are available for the entire United States.

The GIS software used has the built-in capability to translate TIGER files into a compatible format. As a result, a line database consisting of all the street segments as of 1990 for New Castle County, Delaware is presented. In such a line database, each segment of the roadway is defined by a longitude/latitude coordinate pair. Therefore, the spatial relationships between all elements of the database are known. For each segment, attribute data is specified. This attribute information includes the coinciding street name, street type, length, address range, and zip code. Figure 3.1 illustrates the TIGER file base map of New Castle County, Delaware. As can be seen, the map is

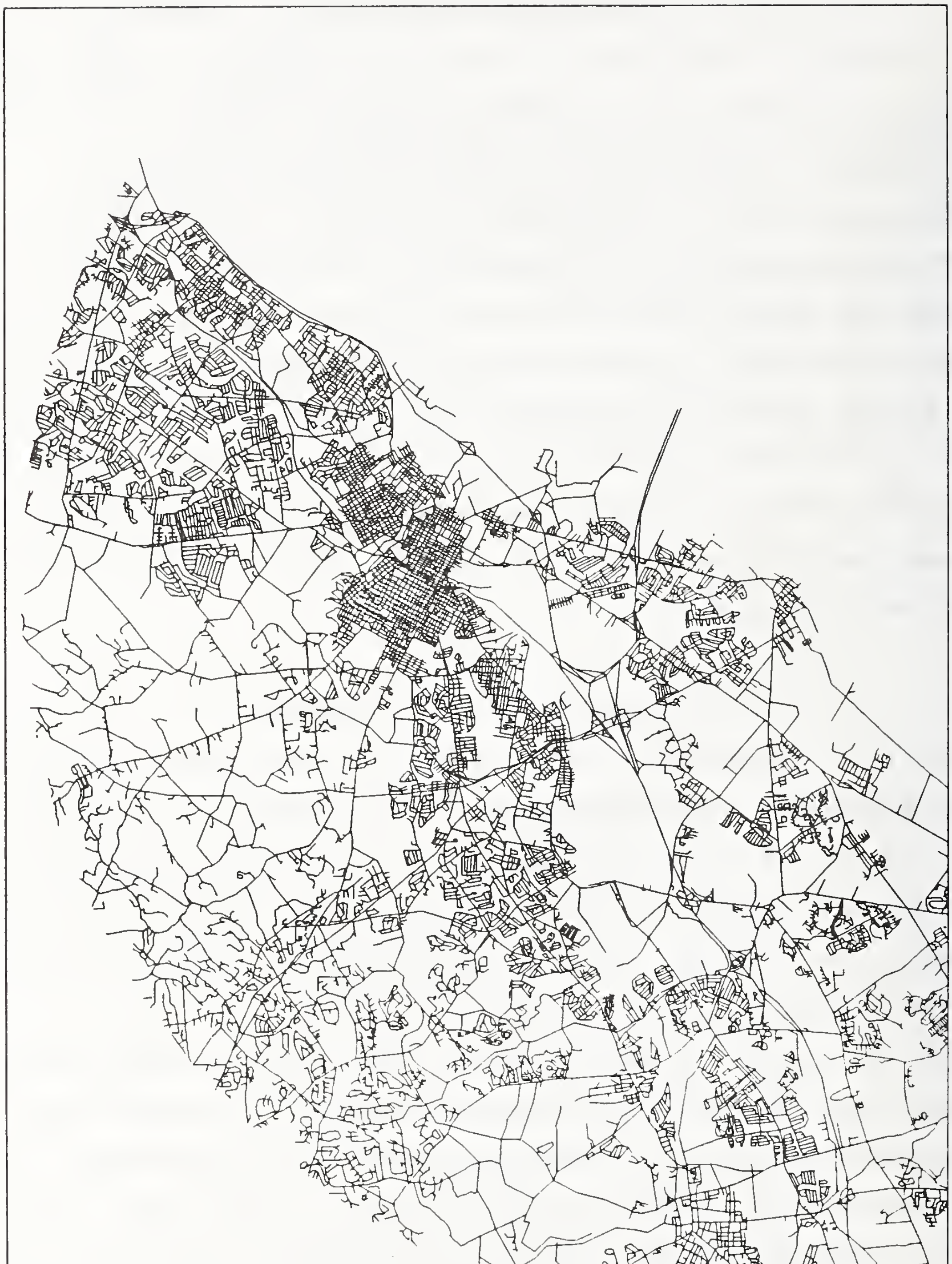


Figure 3.1 TIGER File Base Map

made up of numerous lines. These lines represent the road links (the lines shown in this figure are those selected as the active layers in the GIS software).

3.2 Development of the Bus Route Database

The next step is to develop the DART bus routes database. There are two basic approaches to doing this due to the structure of GIS. The combined set of street segments in the database makes up the segment layer; and likewise, the set of corresponding nodes makes up the node layer. Additional layers can be created consisting of different types of segments or nodes having different attributes. Therefore, the first approach is to make a segment and node layer for each route of the DART system. This is advantageous for the purpose of visual display, since each route can be labeled and displayed separately and in different colors. When necessary, information about a segment pertaining to a particular route can be manipulated for that route only. This approach, however, requires extensive duplication of data since the information about a segment will be stored separately in each layer. In addition, only one layer can be accessed at one time. The segment and node layers for each route are stored in their own database. TransCAD only allows a maximum of 20 separate databases to be active at one time, which is a problem since the DART system has 28 routes (hence 28 layers).

The second approach is to create a selected set for each route and save each set in separate files. The combination of routes can also be saved as a selected file. In this way all the routes will exist in the same layer. From the layer of street segments, each route can be selected from its file or the selection process can based on a condition determined by the value of one attribute. More than one route can be selected based on the union of conditions. Further, shortest path procedures can be performed using any points on the entire bus network. The difficulty when using this approach is trying to distinguish which routes the segments belong to on the map display. One possible method to overcome this is to create an attribute which specifies each route. If a particular segment belongs to the route specified by the attribute, then the value of the attribute will be equal to one. If the segment does not belong to the route, then the value of the attribute will be equal to zero. Having created the DART bus route database, the next step was to develop a database for the bus stops, other landmarks and transit demand locations (presented in the next section). Refer to Figure 3.2 for a computer screen display of the separate layers for each DART route; each of the routes is labeled with the route number (Rt. 6, Rt. 8, etc.) to distinguish it from other routes.

Also refer to Figure 3.3 for a display of a set of selected DART bus routes. This is a macroscopic view as opposed to the microscopic view of a few selected routes in Figure 3.2.

3.3 Development of Bus Stop and Demand Point Database

GIS can be used to display the bus stops. The stops exist in their own node layer which is created from a selected set of nodes on the bus network. Each stop is defined by its latitude/longitude coordinates. As many attributes as desired can be assigned to the bus stop layer. In a similar manner, other locations that are common demand points for transit users can be displayed in their own layers based on information from other databases. Such demand locations include shopping centers, hospitals, parks, hotels, museums, etc. One approach to determining the required location coordinates is to use the geocoding capability of GIS. In this case, addresses of locations were used to pinpoint their location on the GIS map and the corresponding latitude/longitude coordinates were entered into the databases. Figure 3.4 illustrates the selected routes, demand locations (such as museums, hospitals, parks, etc.) and bus stops.

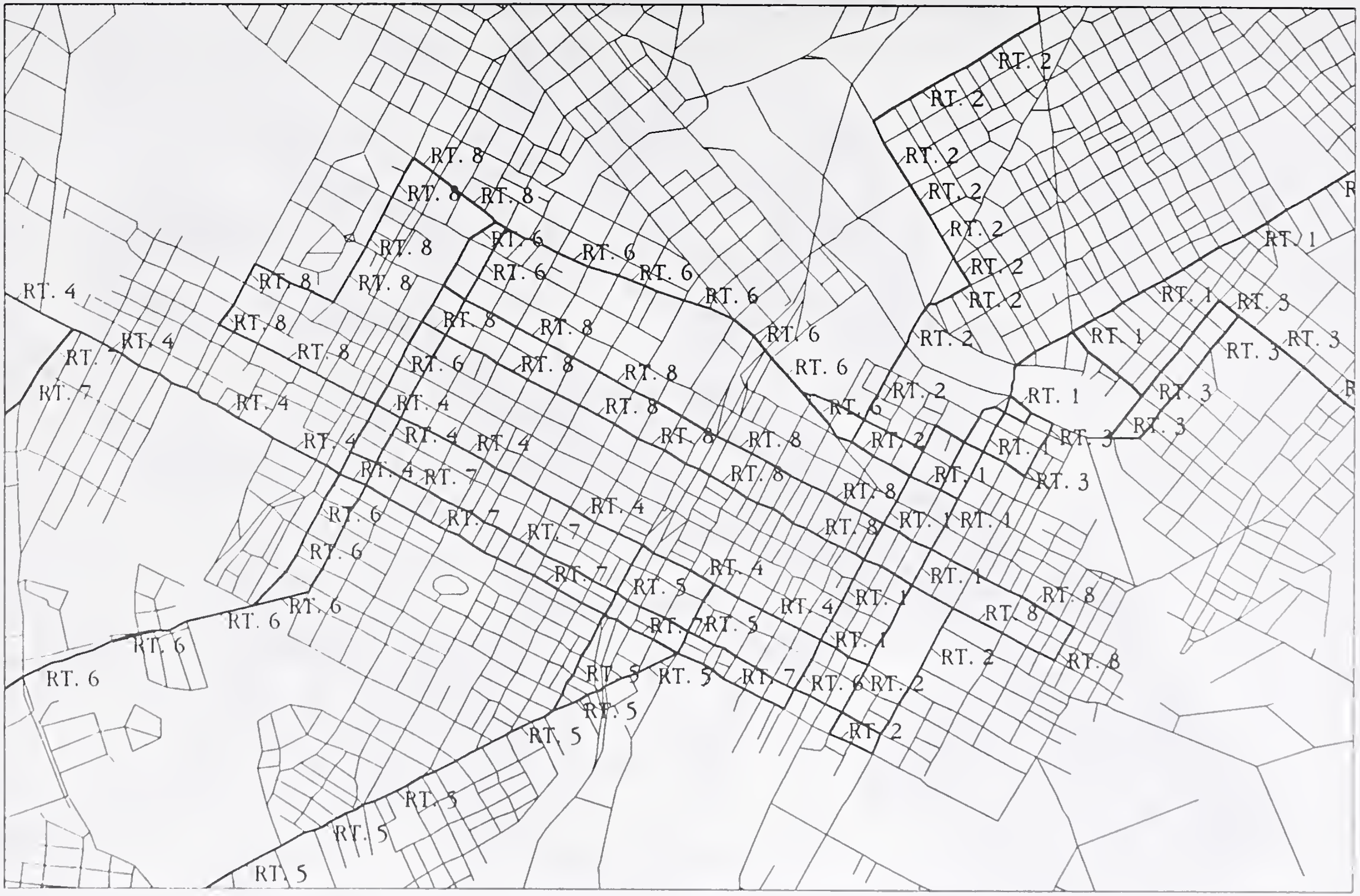


Figure 3.2 Separate Layers for Each DART Route

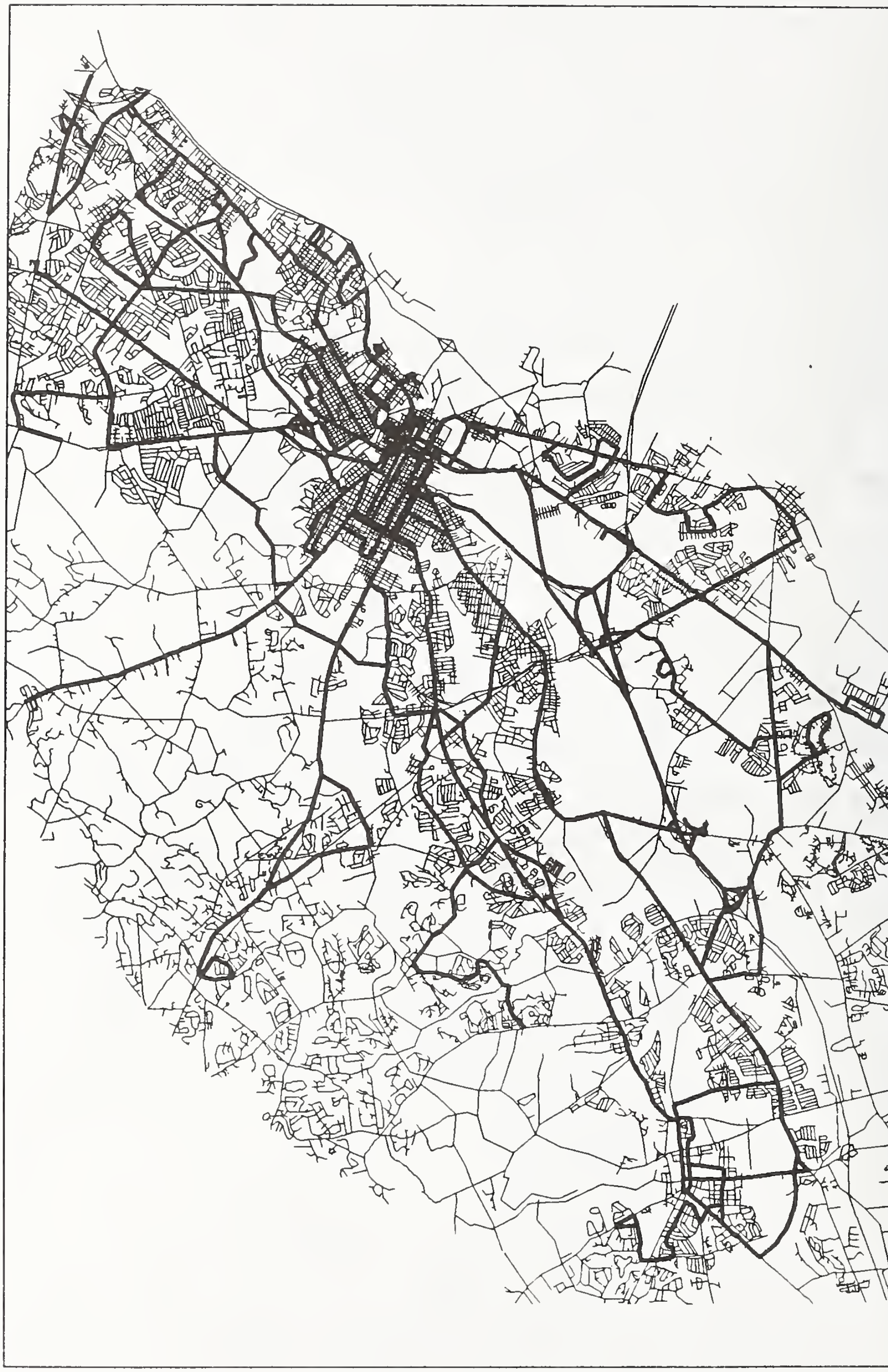


Figure 3.3 Selected Set of DART Routes

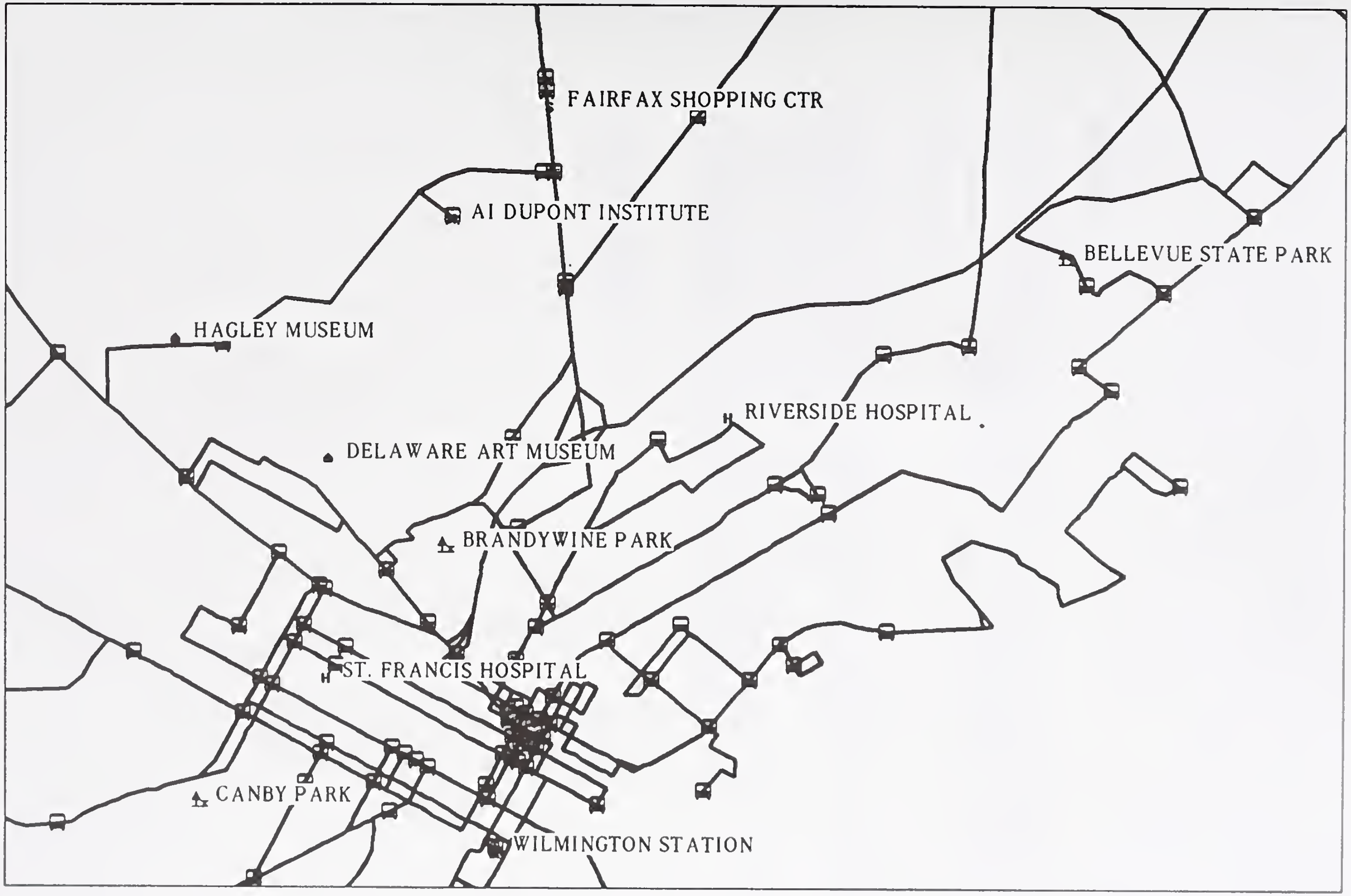


Figure 3.4 Selected Routes, Demand Locations, and Bus Stops

NOTICE

DOT-T-95-07

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Technology Sharing

A Program of the U.S. Department of Transportation